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BECHTEL SAIC COMPANY LLC

Thermal Conductivity of Non-Repository Lithostratigraphic Layers

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2. Type of Mathematical Model

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Describe Intended Use of Model

The model develops values for thermal conductivity, and its uncertainty, for the nonrepository layers of Yucca Mountain; in addition, the model provides estimates for matrix porosity and dry bulk density for the nonrepository layers.

3. Title

Thermal Conductivity of Non-Repository Lithostratigraphic Layers

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MDL-NBS-GS-000006 REV 01

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00	Initial issue
01	Total Revision (no change bars) of this report includes partial rewriting, editing, and reformatting to incorporate Regulatory Integration Team evaluation Phase 1 comments. The revision involves the following activities: 1) Rewriting, reorganizing, or reformatting the report to achieve greater transparency and readability; 2) adding information to more clearly establish the relationships among this report and related reports (either upstream or downstream) and the TSPA; 3) rewriting to incorporate regulatory comments; 4) addressing data traceability, quality, and pedigree issues identified during the Regulatory Integration Team evaluation; 5) Addressing CR#s 2054;79B, and 1821C, 6) Addressing any comments or needed improvements to the assumptions and model validation sections of this report; and 7) Incorporating review comments and developing Appendix V for dry bulk density data qualification.

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ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
AFPL	Aladdin Free Public License
DTN	data tracking number
GFM	Geologic Framework Model
ID	identification
LA	license application
SEP	site and engineering properties
TDMS	Technical Data Management System
TSPA	total system performance assessment
TWP	technical work plan

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1. PURPOSE

This model report addresses activities described in *Technical Work Plan for: Near-Field Environment and Transport Thermal Properties and Analysis Reports Integration* (BSC 2004 [DIRS 171708]). The model develops values for thermal conductivity, and its uncertainty, for the nonrepository layers of Yucca Mountain; in addition, the model provides estimates for matrix porosity and dry bulk density for the nonrepository layers. The studied lithostratigraphic units, as identified in the *Geologic Framework Model (GFM 2000)* (BSC 2004 [DIRS 170029]), are the Timber Mountain Group, the Tiva Canyon Tuff, the Yucca Mountain Tuff, the Pah Canyon Tuff, the Topopah Spring Tuff (excluding the repository layers), the Calico Hills Formation, the Prow Pass Tuff, the Bullfrog Tuff, and the Tram Tuff. The deepest model units of the GFM (Tund and Paleozoic) are excluded from this study because no data suitable for model input are available.

The parameter estimates developed in this report are used as input to various models and calculations that simulate heat transport through the rock mass. Specifically, analysis model reports that use product output from this report are:

- Drift-scale coupled processes (DST and TH seepage) models
- Drift degradation analysis
- Multiscale thermohydrologic model
- Ventilation model and analysis report.

In keeping with the methodology of the thermal conductivity model for the repository layers in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]), the Hsu et al. (1995 [DIRS 158073]) three-dimensional (3-D) cubic model (referred to herein as "the Hsu model") was used to represent the matrix thermal conductivity as a function of the four parameters (matrix porosity, thermal conductivity of the saturating fluid, thermal conductivity of the solid, and geometric connectivity of the solid).

The Hsu model requires input data from each test specimen to meet three specific conditions:

1) Known value for matrix porosity
2) Known values for wet and dry thermal conductivity
3) The location of the measured specimen in relation to the model stratigraphic unit.

The only matrix thermal conductivity values developed are limited to fully saturated and dry conditions. The model does not include the effects of convection and thermal radiation in voids. The model does not include temperature dependence of thermal conductivity, porosity, or bulk density.

Of the geologic formations being modeled by this report, only the Tiva Canyon Tuff is observed to have lithophysal porosity (Rautman and Engstrom 1996 [DIRS 100693], Appendix B). However, the effect of lithophysal porosity on the whole-rock thermal conductivity of the formation is not modeled. This is because the formation is exposed and eroded at the surface. These near-surface effects will have a significant impact on thermal properties and behavior of the Tiva Canyon Tuff. These effects have more significant impact on the layers' thermal behavior than modeling lithophysal porosity. This is documented as a sensitivity analysis, and is presented in Appendix S.

The only deviation from the technical work plan (TWP) (BSC 2004 [DIRS 171708], Section 3.2) concerns the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) acceptance criteria. The TWP states that these acceptance criteria are not relevant to this report because certain outputs are not specifically covered by any category and, instead, provide inputs to downstream numerical models. Contrary to this, the report identifies and discusses the relevant acceptance criteria in Sections 4.2 and 8.2.

2. QUALITY ASSURANCE

Activities associated with the development of this model report were determined to be quality affecting, and subject to the Office of Civilian Radioactive Waste Management quality assurance program (DOE 2004 [DIRS 171539]). Approved quality assurance procedures identified in the TWP (BSC 2004 [DIRS 171708], Section 4) have been used to conduct and document the activities described in this model report. Electronic management of data was evaluated in accordance with procedure AP-SV.1Q, *Control of the Electronic Management of Information*, and the applicable controls are discussed in the TWP (BSC 2004 [DIRS 171708], Section 8.4).

This model report contributes to the analysis and modeling of the unsaturated zone, which is a natural barrier, and is classified on the *Q-List* (BSC 2004 [DIRS 168361] as safety category because it is important to waste isolation, as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List*. The report contributes to the analysis of data used to support performance assessment; the conclusions do not directly impact engineered features important to safety, as defined in AP-2.22Q.

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3. USE OF SOFTWARE

3.1 SOFTWARE TRACKED BY CONFIGURATION MANAGEMENT

The codes subject to Software Configuration Management are listed in Table 3-1, together with a brief description of their functionality. These software packages were obtained from Software Configuration Management and were judged appropriate for intended use with this type of modeling activity based on similar use with other Yucca Mountain Project model development.

SPLICE (STN: 10906-1.0-00 [DIRS 162672]) software was created specifically for this model report. SPLICE examines input files and matches porosity data with wet and dry conductivity data. The matching of data is based on a common sample identification (ID) and common sample depth (allows for a delta of ±1.3 ft). Appendix B provides documentation of SPLICE used to process data for the "NRG" boreholes; Appendix E documents a similar process for data from the "SD" boreholes.

REFORMAT (STN 10907-2.0-00 [DIRS 162673]) software was used to extract and to change the format of text data from the specific data tables listed in Appendices C, D, F, G, and I to P. The range of use of reformat is to change the format and arrangement of the data tables listed in those Appendices.

The parameters documented in this report were constructed, in part, using algorithms that are part of the public-domain Geostatistical Software Library subroutine HISTPLT (STN 10802-2.01-00 [DIRS 158223]) as implemented by Sandia National Laboratories. The software was selected for its ability to display data and statistical functions used to analyze the model results. Section 2.5 of the *Software Management Report, GSLIB HISTPLTV2.01* (SNL 2002 [DIRS 171558]) states the limitations on software and range of parameter values as "Not applicable".

HSUINV (STN: 10804-1.0-00 [DIRS 158228]) was used to solve the inverse problem for the Hsu 3-D cube model of matrix thermal conductivity. Section 2.5 of the S*oftware Management Report, HsuInv, Version 1.0* (SNL 2002 [DIRS 171559]) states the limitations on software the range of parameter values as "Not applicable".

HSUINV (STN: 10804-1.0-00 [DIRS 158228]) and HISTPLT (STN 10802-2.01-00 [DIRS 158223]) were selected, in part, to be compatible with the modeling of thermal conductivity of potential repository layers, and were used for the same purpose and range of validation.

GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) was used to calculate the mean and standard distribution of wet and dry matrix thermal conductivity values as described in Section 6.3 of this model report. Section 2.5 of the *Software Management Report, GENHSUMODELDATA Version 1.00* (SNL 2002 [DIRS 171560]) states:

"There are the following restrictions on the range of parameter values:

For porosity: 0 < ((*phi*)) < 1
For: 0 < ((*gamma c*)) <= 1
For: Ks: ks > 0"

The codes listed in Table 3-1 were run on an Intel personal computer under the Microsoft Windows Server 2000 operating system. Software codes GSLIB HISTPLT (STN: 10802-2.01-00 [DIRS 158223]) and HSUINV (STN: 10804-1.0-00 [DIRS 158228]) were qualified in accordance with AP-SI.1Q, Rev 3, ICN 3, *Software Management*. Software codes GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]), REFORMAT (STN 10907-2.0-00 [DIRS 162673]), and SPLICE (STN: 10906-1.0-00 [DIRS 162672]) were qualified in accordance with AP-SI.1Q Rev 3, ICN 4, *Software Management.* All software codes were used within their range of validation.

Table 3-1. Software Tracked by Software Configuration Management

Code Name	Version	STN Number	Platform	Operating System	Brief Description
GSLIB HISTPLT [DIRS 158223]	V. 2.01	10802-2.01-00	PC	Microsoft Windows Server 2000	Generates univariate statistical summaries and histograms that are compatible with a PostScript display device.
HSULNV [DIRS 158228]	V. 1.0	10804-1.0-00	PC	Microsoft Windows Server 2000	The code solves the inverse problem for Hsu et al. (1995 [DIRS 158073]) 3-D cube model of matrix thermal conductivity. The inverse problem consists of simultaneously solving two nonlinear equations.
REFORMAT [DIRS 162673]	V. 2.0	10907-2.0-00	PC	Microsoft Windows Server 2000	Extracts columns of data from one or more input files to an output file or from one input file to one or more output files. Lithostratigraphy can be added to the output file(s) if borehole ID and depth are available.
GENHSUMODE LDATA [DIRS 162671]	V. 1.0	10905-1.0-00	PC	Microsoft Windows Server 2000	Takes distributions of matrix porosity, solid thermal conductivity, and Hsu model geometry parameter gamma_c, and calculates the mean and standard distribution of wet and dry matrix thermal conductivities.
SPLICE [DIRS 162672]	V. 1.0	10906-1.0-00	PC	Microsoft Windows Server 2000	Combines a file of porosity data with a file of wet and dry thermal conductivity data, based on a common sample ID.

NOTES: All software was run on a 530 Work Station model CPU barcode R436032 manufactured by Dell.
CPU = central processing unit; PC = personal computer; STN = Software Tracking Number.

3.2 EXEMPT SOFTWARE

In accordance with Section 2.1 of LP-SI.11Q-BSC, *Software Management*, exempt software products include operating systems, utilities, compilers and their associated libraries, spreadsheets, database managers, graphical representations of data, computer-aided design systems, acquired software that is embedded in the test and measurement equipment, and the standard functions of commercial off-the-shelf software. The following exempt software were used in the development of the modeling activities discussed in this modeling report or the display of modeling results. All exempt software was run on a Microsoft Windows 2000 server.

- Aladdin Free Public License (AFPL) Ghostscript Version 7.04 is software that provides an interpreter for the PostScript language with the ability to convert PostScript language files to many raster formats, view them on displays, print them on non-PostScript printers, and act as an interpreter for Portable Document Format. Ghostscript also has the ability to convert back and forth between PostScript language and Portable Document Format files.

- Digital Visual Fortran Version 5.0 is a Fortran 90 compiler for Windows. Digital Visual Fortran is a complete development system that includes Digital's Fortran 90 compiler, a visual development environment from Microsoft, and support for numerous industry-standard Fortran-language extensions.

- GSView Version 4.2 is a graphical interface for Ghostscript. GSView allows encapsulated postscript plot files to be viewed or printed. GSView requires AFPL Ghostscript.

- Microsoft Excel 2000 is a spreadsheet application used to sort and count data, and to perform linear regressions for the model validation.

- MATHCAD Professional 11.2a is used in Appendix S for graphical representation and arithmetic manipulation.

Attachment 2, Item 3 of AP-SIII.10Q, *Models*, requests four pieces of information for exempt software:

- The formula or algorithm used

- A listing of the inputs to the formula or algorithm

- A listing of the outputs from the formula or algorithm

- Other information (e.g., operating environment information) that would be required in order to independently reproduce the work.

For AFPL Ghostscript Version 7.04, Digital Visual FORTRAN Version 5.0, and GSView Version 4.2, the user provides no formulas or algorithms, and knowledge of the internal algorithms in these applications is not necessary to use them.

Any formulas used in Microsoft Excel 2000 are provided in this report, where the inputs and outputs are identified.

The inputs to GSView Version 4.2 are encapsulated postscript files prepared from the postscript plots produced by the histogram plotter HISTPLT (STN 10802-2.01-00 [DIRS 158223]). The postscript plots from HISTPLT (STN 10802-2.01-00 [DIRS 158223]) are modified with an editor, to remove the first three lines. This converts the postscript to encapsulated postscript.

All formulas used by MATHCAD Professional 11.2a are fully documented and described in Appendix S.

To access the encapsulated postscript file, the option “Open” is selected from the GSView “File” menu. From the “Edit” menu, the option “Add EPS Preview” is selected, and “TIFF 6 uncompressed” is selected from the resulting submenu. The plot is converted, and GSView prompts the user for a name (filename) for the output file. The user should add the suffix .eps to the chosen filename. The plot is displayed in the lower-left portion of the window (to view the plot, it may be necessary to use the scroll bars to “scroll” down to that part of the window).

The actual work is done by AFPL Ghostscript Version 7.04. GSView provides a Windows-style interface to Ghostscript. The output files are suitable to be included in a Microsoft Word document.

4. INPUTS

4.1 DIRECT INPUTS

Direct inputs to the Hsu model (Hsu et al. 1995 [DIRS 158073]) are matrix porosity and thermal conductivity. The model also requires a stratigraphic coordinate system that represents the relative position of each model unit for which the measured data are used.

The Site and Engineering Properties (SEP) parameters “porosity” and “thermal conductivity” were searched for all qualified, verified data tables. Data tables containing data exclusively for the repository layers or for materials other than geologic layers (e.g., titanium or grout) were excluded from consideration because the scope of the model is the nonrepository geologic layers of Yucca Mountain. Only data tables that included lithostratigraphy and depth, and either borehole ID or sample ID, were retained for consideration, because one of these items is necessary to determine the lithostratigraphic layer. Porosity data other than matrix porosity data were excluded from consideration because the Hsu model requires matrix porosity and wet and dry thermal conductivity as inputs. Matrix porosity data are obtained from laboratory core measurements. It is worth distinguishing between matrix porosity, which is due to interstitial porosity between grains, and whole rock porosity, which is structurally controlled by regional fracturing.

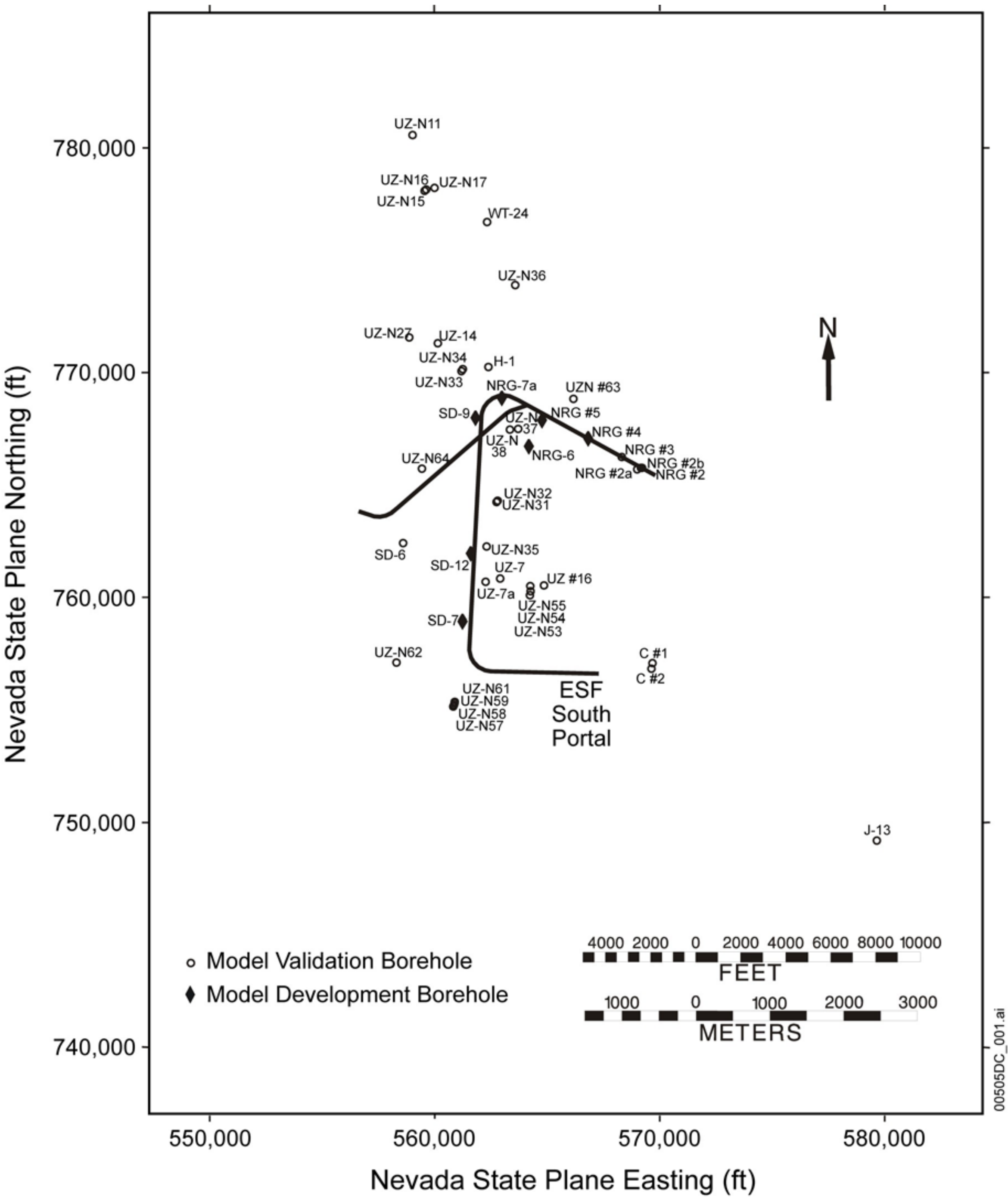
Figure 4-1 shows the location of 44 boreholes in the Yucca Mountain region that supplied rock specimens used for parameter measurements. Boreholes that were chosen for model input are shown as black diamonds; boreholes that supplied core used for model validation are shown as open circles. Appendix T lists these boreholes and their casing elevation and Nevada State Plane coordinates.

Qualified, verified matrix porosity and thermal conductivity data are used to generate the Hsu model for thermal conductivity for the nonrepository layers of the Yucca Mountain site.

1. Data tables in the SEP database of the Yucca Mountain Project Technical Data Management System (TDMS) provided the material properties (matrix porosity, dry and saturated matrix thermal conductivity) used to construct the thermal conductivity model.

2. DTNs: MO0004QGFMPICK.000 [DIRS 152554] and SNF40060298001.001 [DIRS 107372] are used to correlate the location of matrix porosity and thermal conductivity to the stratigraphic units defined in Table U-1 of Appendix U of this report.

3. The range of values for the thermal conductivity of solid glass was taken from the *Chemical Engineers' Handbook* (Perry and Chilton 1973 [DIRS 104946], p. 3-260).



Source: DTNs: MO9906GPS98410.000 [DIRS 109059], MO9905LUSWWT24.000 [DIRS 165921], MO9912GSC99492.000 [DIRS 165922].

NOTES: Prefixes UE-25 and USW are omitted from borehole names because of spacing constraints. Complete names are listed in Appendix T.

Unqualified data, and data not available as triads, are also used in model validation.

Figure 4-1. Location of Boreholes Used for the Thermal Conductivity Study

The thermal conductivity model applies to the nonrepository stratigraphic units of the GFM as described in Appendix U, Table U-1. The construction of the thermal conductivity model requires matrix porosity and dry and saturated matrix thermal conductivities for the same location. These triads of data are obtained from qualified and verified data tracking numbers (DTNs) in TDMS. The triads are processed by the inverse code HSUINV (STN 10804-1.0-00 [DIRS 158228]) to generate solid thermal conductivity and a geometric parameter (gamma_c or γ_c). The development of the thermal conductivity model also uses matrix porosity data for the stratigraphic model units listed in Table U-1. Only qualified and verified matrix porosity data are used. The data used in model validation require porosity and either dry or saturated thermal conductivity, or else porosity and in situ saturation and thermal conductivity. These data are obtained from qualified, verified DTNs in TDMS. The probability distributions for solid thermal conductivity, γ_c, and porosity are used by GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) to generate the model data.

4.1.1 Lithostratigraphic Contacts

Lithostratigraphic contacts can be established from observations based on core specimens, petrophysical logs, or borehole video logs. The DTNs which include this type of information are shown in Table 4-1.

Table 4-1. Source of Input for Observed Lithostratigraphic Contacts

Data Source Description	Reference
Lithostratigraphic Contacts (multiple boreholes)	DTN MO0004QGFMPICK.000 [DIRS 152554]
Lithostratigraphic Contacts (USW SD-6)	DTN SNF40060298001.001 [DIRS 107372]

Definitions of the lithostratigraphic layers are given in the DTNs cited in Table 4-1. The GFM units from Table U-1 are identified as divisions of lithostratigraphic subzones whose contact depths are available from Table 4-1 DTNs. Because the 31 matrix porosity, wet thermal conductivity, and dry thermal conductivity data triads (Table 4-2) do not provide data for all of the Table U-1 units shown, it is necessary to group the units into larger categories: welded, non-welded, vitric, and calico. The assignment of Table U-1 model units to one of these categories is based on the textural description of the lithostratigraphic subzone in DTN MO0004QGFMPICK.000 [DIRS 152554]. Vitric, densely welded subzones are classified as vitric. Non-welded and moderately welded vitric subzones are classified as “non-welded.” Welded subzones are classified as welded. Subzones of the Calico Hills Formation are classified as calico. The remaining subzones above the Calico Hills Formation are classified as non-welded. The lithostratigraphic units below the Calico Hills Formation (i.e., the Tram, Bullfrog, and Prow Pass tuffs) are divided into welded and non-welded subzones for the “Prow Pass,” “Bullfrog,” and “Tram Tuff,” respectively. The correlation of GFM units to layer characterization is shown in Table 4-2. Because more porosity data are available, ten unique rock types are characterized for matrix porosity. Conversely, fewer thermal-conductivity input data are available; therefore, only four unique rock types are characterized.

Table 4-2. Layer Characterization of the GFM

GFM Units (from Table U-1)	Layer Characterization for Matrix Porosity	Layer Characterization for Thermal Conductivity	Triad Count[a,b]
Crystal-rich Tiva/Post-Tiva, Tpcp, TpcLD	welded	welded	6
Tpcpv3	vitric	vitric	0
Tpcpv1, Tpcpv2, Tpbt4, Yucca, Tpbt3_dc, Pah, Tpbt2, Tptrv3, Tptrv2	non-welded	non-welded	9
Tptrv1	vitric	vitric	0
Tptrl, Tptrn, and Tptf	welded	welded	11
Tptpv3	vitric	vitric	0
Tptpv1, Tptpv2, Tpbt1	non-welded	non-welded	0
Calico, Calicobt	calico	calico	5
Prowuv, Prowuc	Prow Pass Hills non-welded	non-welded	0
Prowmd	Prow Pass Hills welded	welded	0
Prowlv, Prowlc, Prowbt	Prow Pass Hills non-welded	non-welded	0
Bullfroguv, Bullfroguc	Bullfrog non-welded	non-welded	0
Bullfrogmd	Bullfrog welded	welded	0
Bullfroglc, Bullfroglv, Bullfrogbt	Bullfrog non-welded	non-welded	0
Tramuv, Tramuc	Tram Tuff non-welded	non-welded	0
Trammd	Tram Tuff welded[c]	welded	0
Tramlc, Tramlv, Trambt	Tram Tuff non-welded	non-welded	0

Source: *Geologic Framework Model (GFM2000)* (BSC 2004 [DIRS 170029], Table 6-2).

Column triad count was produced by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using the data from
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

[a] Zero count indicates lack of wet matrix thermal conductivity, dry matrix thermal conductivity, and porosity data acquired from rock samples collected at a single location.

[b] A complete triad count and listing of associated data are provided in Table 6-13.

[c] Matrix porosity values from the Prow Pass Welded layer are substituted for those of the Tram Tuff welded layer because no data are available for the Tram Tuff welded layer.

4.1.2 Matrix Porosity Data

Matrix porosity data for Boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6 and USW NRG-7/7a, USW SD-7, USW SD-9 and USW SD-12 are the only qualified data available that can be paired with qualified dry and saturated matrix thermal conductivity data. The data for UE-25 NRG #5 are located in the repository horizons and are not of interest for this model report. The sources of matrix porosity are shown in Table 4-3.

Table 4-3. Sources of Matrix Porosity Data for Thermal Conductivity Model Input

Data Source Description	Reference DTN	Data Table
Matrix porosity data for Boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6 and USW NRG-7/7a	SNL01A05059301.007 [DIRS 108980]	S98424_003
Matrix porosity data for Borehole USW NRG-6	GS000508312231.006 [DIRS 153237]	S00415_001
Matrix porosity data for Boreholes USW SD-7, USW SD-9, and USW SD-12	MO0109HYMXPROP.001 [DIRS 155989]	S01144_001 (file *DATAQ.zip*)
Matrix porosity data for Borehole USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_001
Matrix porosity data for Borehole USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_005
Matrix porosity data for Borehole USW NRG-6	SNL02030193001.022 [DIRS 109613]	S99111_001

4.1.3 Matrix Thermal Conductivity

Qualified and verified matrix thermal conductivity data that can be paired with matrix porosities are used as input to the inverse code HSUINV (STN 10804-1.0-00 [DIRS 158228]) to generate solid thermal conductivity distributions and a geometric parameter. These distributions are used to build the thermal conductivity model. The thermal conductivity DTNs used to develop the thermal conductivity model are shown in Table 4-4.

Table 4-4. Sources of Qualified, Verified Matrix Thermal Conductivity Data

Data Source Description	Reference DTN	Data Table
Matrix thermal conductivity data for Boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, and USW NRG-7/7a	SNL01A05059301.005 [DIRS 109002]	S96370_001
Matrix thermal conductivity data for Boreholes USW SD-7, USW SD-9, and USW SD-12	SNL22100196001.006 [DIRS 158213]	S98169_002

4.1.4 Thermal Conductivity of Solid Glass

There are no DTNs that contain vitric data triads (porosity, wet and dry thermal conductivities), so there are no inputs for the inverse code HSUINV (STN 0804-1.0-00 [DIRS 158228]). HSUINV (STN 0804-1.0-00 [DIRS 158228]) generates solid thermal conductivity and geometry factor values, but the solid thermal conductivity and geometry factor can be estimated from other sources. A range of solid thermal conductivity for solid glass (0.35 to 1.26 W/m K) is taken from the *Chemical Engineers' Handbook* (Perry and Chilton 1973 [DIRS 104946], Table 3-260).

4.1.5 Dry Bulk Density

Dry bulk density measurements are used to develop product outputs shown in Table 6-13. However, the measurements are not direct input to the Hsu model; they were processed using the REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) code to assign model layers in accordance with the lithostratigraphic correlation table given in Appendix U. The resulting output is included in Table 6-13 and output DTN SN0303T0503102.008; therefore, the dry bulk density measurements listed in Table 4-5 are considered direct input for this model report.

In the absence of validation thermal conductivity data for several of the layers, it is necessary to calculate validation data by a regression of existing qualified, verified data. Porosity and dry bulk density are used as variables in the regression. The data regression is described in Section 7.2, and is supported by documentation provided in Appendix Q and Appendix R. Dry bulk density data are available from 48 data tables from 37 DTNs. The DTNs are given in Table 4-5.

Supporting documentation for the processing of dry bulk density data is provided in Section 6.7 and in Appendix L. Appendix V documents the qualification of two "unqualified" dry bulk density data sets (GS920408312314.011 [DIRS 129660] and GS930408312132.007 [DIRS 129625]) intended for use in this model report (see Table 6-13).

Table 4-5. Sources of Dry Bulk Density

Data Source Description	Reference DTN	Data Table
Dry bulk density data for USW UZ-N11 to USW UZ-N64	GS000408312231.004 [DIRS 149582]	S00276_001
Dry bulk density data for USW NRG-6	GS000508312231.006 [DIRS 153237]	S00415_001
Dry bulk density data for USW SD-12 and radial boreholes	GS950308312231.002 [DIRS 108990]	S96015_001
Dry bulk density data for USW SD-9	GS950408312231.004 [DIRS 108986]	S96021_001
Dry bulk density data for UE-25 UZ #16	GS940508312231.006 [DIRS 107149]	S96024_003
Dry bulk density data for USW UZ-N53	GS930108312231.006 [DIRS 108997]	S96025_001
Dry bulk density data for USW UZ-N54 and USW UZ-N55	GS920508312231.012 [DIRS 109001]	S96026_001
Dry bulk density data for USW UZ-N57, USW UZ-N61, USW UZ-N62	GS940408312231.004 [DIRS 109000]	S96027_001
Dry bulk density data for USW SD-7	GS951108312231.009 [DIRS 108984]	S96037_001
Dry bulk density data for USW NRG-7/7a	GS951108312231.010 [DIRS 108983]	S96046_001
Dry bulk density data for USW UZ-7a	GS951108312231.011 [DIRS 108992]	S96049_001
Dry bulk density data for USW SD-7 and USW SD-12	GS960808312231.004 [DIRS 108985]	S97058_001
Dry bulk density data for USW H-1	GS920408312314.011 [DIRS 129660]	S97135_002
Dry bulk density data for UE-25 J-13	GS930408312132.007 [DIRS 129625]	S97276_001
Dry bulk density data for USW WT-24	GS980708312242.010 [DIRS 106752]	S98248_004
Dry bulk density data for USW SD-6	GS980808312242.014 [DIRS 106748]	S98285_001
Dry bulk density data for UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, USW NRG-7/7a	SNL01A05059301.007 [DIRS 108980]	S98424_001
Dry bulk density data for USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_001
Dry bulk density data for USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_002
Dry bulk density data for USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_004
Dry bulk density data for USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_005
Dry bulk density data for USW NRG-6	SNL02030193001.004 [DIRS 108415]	S98485_001
Dry bulk density data for USW NRG-6	SNL02030193001.004 [DIRS 108415]	S98485_003
Dry bulk density data for USW NRG-6	SNL02030193001.008 [DIRS 120597]	S98486_001
Dry bulk density data for UE-25 NRG #2	SNL02030193001.003 [DIRS 120578]	S99100_001

Table 4-5. Sources of Dry Bulk Density (Continued)

Data Source Description	Reference DTN	Data Table
Dry bulk density data for UE-25 NRG #2	SNL02030193001.003 [DIRS 120578]	S99100_004
Dry bulk density data for UE-25 NRG #2a	SNL02030193001.006 [DIRS 120579]	S99101_001
Dry bulk density data for UE-25 NRG #2a	SNL02030193001.006 [DIRS 120579]	S99101_004
Dry bulk density data for UE-25 NRG #2b	SNL02030193001.013 [DIRS 120614]	S99104_001
Dry bulk density data for UE-25 NRG #2b	SNL02030193001.013 [DIRS 120614]	S99104_004[a]
Dry bulk density data for UE-25 NRG #3	SNL02030193001.005 [DIRS 122545]	S99105_001
Dry bulk density data for UE-25 NRG #3	SNL02030193001.005 [DIRS 122545]	S99105_004[b]
Dry bulk density data for UE-25 NRG #3	SNL02030193001.007 [DIRS 120582]	S99106_001
Dry bulk density data for UE-25 NRG #4	SNL02030193001.014 [DIRS 109609]	S99107_001
Dry bulk density data for UE-25 NRG #4	SNL02030193001.014 [DIRS 109609]	S99107_004
Dry bulk density data for UE-25 NRG #4	SNL02030193001.015 [DIRS 120617]	S99108_001
Dry bulk density data for UE-25 NRG #5	SNL02030193001.009 [DIRS 109614]	S99109_001[c]
Dry bulk density data for UE-25 NRG #5	SNL02030193001.012 [DIRS 108416]	S99110_001
Dry bulk density data for USW NRG-6	SNL02030193001.022 [DIRS 109613]	S99111_002
Dry bulk density data for USW NRG-7/7a	SNL02030193001.016 [DIRS 120619]	S99112_001
Dry bulk density data for USW NRG-7/7a	SNL02030193001.017 [DIRS 109610]	S99113_001
Dry bulk density data for USW NRG-7/7a	SNL02030193001.018 [DIRS 109611]	S99114_001
Dry bulk density data for USW NRG-7/7a	SNL02030193001.019 [DIRS 108431]	S99115_001
Dry bulk density data for USW NRG-7/7a	SNL02030193001.019 [DIRS 108431]	S99115_002
Dry bulk density data for USW NRG-7/7a	SNL02030193001.020 [DIRS 108432]	S99116_001
Dry bulk density data for USW NRG-7/7a	SNL02030193001.020 [DIRS 108432]	S99116_004
Dry bulk density data for USW NRG-7/7a	SNL02030193001.021 [DIRS 108433]	S99117_001
Dry bulk density data for USW NRG-6	SNL01A05059301.002 [DIRS 150042]	S99435_001

[a] Data table S99104_004 was excluded because the data are for an alluvium layer not considered in this report.
[b] Data table S99105_004 was excluded because the lithostratigraphy correlation data (DTN MO0004QGFMPICK.000 [DIRS 152554]) are not available for UE-25 NRG #3.
[c] Data table S99109_001 was excluded because the data are for the repository layers not considered in this report.

4.2 CRITERIA

The *Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275]) includes the following criterion that is relevant to the work documented in this report:

- PRD-002/T-015 Requirements for Performance Assessment; see 10 CFR 63.114 [DIRS 156605] for complete requirement text.

Work described in this model report supports these requirements, but more-specific criteria exist in the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]). The criteria established for the quantity and chemistry of water contacting engineered barriers and waste forms as presented in Section 2.2.1.3.3.3 of *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) and 10 CFR 63.114(a)-(c) and (e)-(g) [DIRS 156605] are applicable to this model report.

4.2.1 Acceptance Criteria

The acceptance criteria relevant to this model report are presented in Section 4.2.1 of this report, and an assessment of how the criteria are addressed is provided in Section 8.2 of this report.

Acceptance Criterion 2 – Data are Sufficient for Model Justification

(1) Geological, hydrological, and geochemical values used in the license application are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided.

Acceptance Criterion 3 – Data Uncertainty Is Characterized and Propagated Through the Model Abstraction

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

(2) Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers and waste forms are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large block and drift-scale heater and niche tests), and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.

Acceptance Criterion 4 – Model Uncertainty is Characterized and Propagated Through the Model Abstraction

(2) Alternative modeling approaches are considered and the selected modeling approach is consistent with available data and current scientific understanding. A description that includes a discussion of alternative modeling approaches not considered in the final analysis and the limitations and uncertainties of the chosen model is provided;

4.2.2 Completion Criteria

Section 3.4 of the TWP (BSC 2004 [DIRS 171708]) addresses completion criteria for this report, and specifically requires that work be done to address Condition Report #2054. The condition report was written because some of the dry bulk density data used as direct input in this report were downgraded to unqualified status after this report was first issued. Appendix V documents the qualification of two unqualified data sets intended for use in this model report.

Section 1.2.2 of the TWP (BSC 2004 [DIRS 171708]) describes the revision of this report as partial rewriting, editing, and reformatting to incorporate Regulatory Integration Team evaluation Phase 1 comments.

4.3 CODES, STANDARDS, AND REGULATIONS

This report was prepared to comply with 10 CFR Part 63 [DIRS 156605], the U.S. Nuclear Regulatory Commission rule on high-level radioactive waste. Subparts of this rule that are applicable to data and models include Subpart E, Section 114 (Requirements for Performance Assessment).

4.4 INDIRECT INPUT DATA USED FOR MODEL VALIDATION

Indirect input data include those data that are used to validate the Hsu model. It should be noted that the same DTN and SEP table may appear in the tables for direct input and also indirect input. In these cases, data extracted from SEP for model input were unique and separate from data used for model validation (e.g., unique sample numbers differing from core extraction depths within the same SEP table).

4.4.1 Matrix Porosity

Matrix porosity data used to evaluate the average porosity for the layer categories come from boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, USW NRG-7/7a, USW SD-7, USW SD-9, and USW SD-12 from the six DTNs listed in Table 4-3. These data include 487 welded porosities, 72 vitric porosities, 307 non-welded porosities, 258 Calico porosities, 55 Prow Pass welded porosities, 421 Prow Pass non-welded porosities, 87 Bullfrog welded porosities, 54 Bullfrog non-welded porosities, and 26 Tram Tuff non-welded porosities. These porosity data do not have corresponding thermal conductivity data because they are used to compute an average porosity; the porosity data are not used by the inverse code HSUINV (STN 10804-1.0-00 [DIRS 158228]).

Porosity data from 40 DTNs (57 data tables) are used to verify that the porosities used in building the Hsu model are representative of all the remaining porosities. The DTNs and data table numbers are shown in Table 4-6.

Table 4-6. Sources of Matrix Porosity Data Used to Validate the "Representative Data" Assumption

Data Source Description	Reference DTN	Data Table
Matrix porosity data for various Boreholes USW UZ-N11 to USW UZ-N64 (see Figure 4-1), UE-25 UZN #63	GS000408312231.004 [DIRS 149582]	S00276_001
Matrix porosity data for Boreholes UE-25 c#1 and UE-25 c#2	MO0012POROCHOL.000 [DIRS 153376]	S00452_001
Matrix porosity data for various Boreholes USW UZ-N11 to USW UZ-N64, USW NRG-6, USW NRG-7, USW SD-7, USW SD-9, USW SD-12	MO0109HYMXPROP.001 [DIRS 155989]	S01144_001 (file *DATAQ.zip*)
Matrix porosity data for Borehole USW SD-7	MO0109HYMXPROP.001 [DIRS 155989]	S01144_032 (file *DATAQ.zip*)

Table 4-6. Sources of Matrix Porosity Data Used to Validate the "Representative Data" Assumption (Continued)

Data Source Description	Reference DTN	Data Table
Matrix porosity data for Borehole USW UZ-14	MO0109HYMXPROP.001 [DIRS 155989]	S01144_033 (file *DATAQ.zip*)
Matrix porosity data for Borehole USW UZ-16	MO0109HYMXPROP.001 [DIRS 155989]	S01144_034 (file *DATAQ.zip*)
Matrix porosity data for Borehole USW SD-12 and radial boreholes	GS950308312231.002 [DIRS 108990]	S96015_001
Matrix porosity data for borehole USW SD-12 and radial boreholes	GS950308312231.002 [DIRS 108990]	S96015_002
Matrix porosity data for borehole USW SD-9	GS950408312231.004 [DIRS 108986]	S96021_002
Matrix porosity data for borehole UE-25 UZ #16	GS940508312231.006 [DIRS 107149]	S96024_002
Matrix porosity data for borehole USW UZ-N53	GS930108312231.006 [DIRS 108997]	S96025_002
Matrix porosity data for borehole USW UZ-N54 and USW UZ-N55	GS920508312231.012 [DIRS 109001]	S96026_002
Matrix porosity data for borehole USW UZ-N57, USW UZ-N61, USW UZ-N62	GS940408312231.004 [DIRS 109000]	S96027_002
Matrix porosity data for borehole USW SD-7	GS951108312231.009 [DIRS 108984]	S96037_002
Matrix porosity data for borehole USW NRG-7/7a	GS951108312231.010 [DIRS 108983]	S96046_001
Matrix porosity data for borehole USW UZ-7/7a	GS951108312231.011 [DIRS 108992]	S96049_001
Matrix porosity data for borehole USW SD-7 and USW SD-12	GS960808312231.004 [DIRS 108985]	S97058_002
Matrix porosity data for borehole USW H-1	GS920408312314.011 [DIRS 129660]	S97135_007
Matrix porosity data for borehole UE-25 J-13	GS930408312132.007 [DIRS 129625]	S97276_003
Matrix porosity data for borehole USW WT-24	GS980708312242.010 [DIRS 106752]	S98248_006
Matrix porosity data for borehole USW SD-6	GS980808312242.014 [DIRS 106748]	S98285_002
Matrix porosity data for boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, USW NRG-7/7a	SNL01A05059301.007 [DIRS 108980]	S98424_003
Matrix porosity data for borehole USW NRG-6	SNL02030193001.001 [DIRS 120572]	S98483_001
Matrix porosity data for borehole USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_002
Matrix porosity data for borehole USW NRG-6	SNL02030193001.002 [DIRS 120575]	S98484_004
Matrix porosity data for borehole USW NRG-6	SNL02030193001.004 [DIRS 108415]	S98485_001
Matrix porosity data for borehole USW NRG-6	SNL02030193001.004 [DIRS 108415]	S98485_003
Matrix porosity data for borehole USW NRG-6	SNL02030193001.004 [DIRS 108415]	S98485_005
Matrix porosity data for borehole USW NRG-6	SNL02030193001.008 [DIRS 120597]	S98486_001
Matrix porosity data for borehole UE-25 NRG #2	SNL02030193001.003 [DIRS 120578]	S99100_001
Matrix porosity data for borehole UE-25 NRG #2	SNL02030193001.003 [DIRS 120578]	S99100_004
Matrix porosity data for borehole UE-25 NRG #2a	SNL02030193001.006 [DIRS 120579]	S99101_001
Matrix porosity data for borehole UE-25 NRG #2a	SNL02030193001.006 [DIRS 120579]	S99101_004
Matrix porosity data for borehole UE-25 NRG #2b	SNL02030193001.013 [DIRS 120614]	S99104_001
Matrix porosity data for borehole UE-25 NRG #2b	SNL02030193001.013 [DIRS 120614]	S99104_004 [a]
Matrix porosity data for borehole UE-25 NRG #2b	SNL02030193001.013 [DIRS 120614]	S99104_005
Matrix porosity data for borehole UE-25 NRG #3	SNL02030193001.005 [DIRS 122545]	S99105_001
Matrix porosity data for borehole UE-25 NRG #3	SNL02030193001.005 [DIRS 122545]	S99105_004 [b]
Matrix porosity data for borehole UE-25 NRG #3	SNL02030193001.007 [DIRS 120582]	S99106_001

Table 4-6. Sources of Matrix Porosity Data Used to Validate the "Representative Data" Assumption (Continued)

Data Source Description	Reference DTN	Data Table
Matrix porosity data for borehole UE-25 NRG #4	SNL02030193001.015 [DIRS 120617]	S99108_001
Matrix porosity data for borehole UE-25 NRG #5	SNL02030193001.009 [DIRS 109614]	S99109_001 [c]
Matrix porosity data for borehole UE-25 NRG #5	SNL02030193001.009 [DIRS 109614]	S99109_002
Matrix porosity data for borehole UE-25 NRG #5	SNL02030193001.012 [DIRS 108416]	S99110_001
Matrix porosity data for borehole USW NRG-6	SNL02030193001.022 [DIRS 109613]	S99111_002
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.016 [DIRS 120619]	S99112_001
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.017 [DIRS 109610]	S99113_001
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.017 [DIRS 109610]	S99113_003
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.018 [DIRS 109611]	S99114_001
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.019 [DIRS 108431]	S99115_001
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.019 [DIRS 108431]	S99115_002
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.020 [DIRS 108432]	S99116_001
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.020 [DIRS 108432]	S99116_004
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.020 [DIRS 108432]	S99116_006
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.021 [DIRS 108433]	S99117_001
Matrix porosity data for borehole USW NRG-7/7a	SNL02030193001.021 [DIRS 108433]	S99117_005
Matrix porosity data for borehole USW SD-9	SNL02030193001.028 [DIRS 159972]	S99121_001
Matrix porosity data for borehole USW NRG-6	SNL01A05059301.002 [DIRS 150042]	S99435_001

[a] Data table S99104_004 was excluded because the data are for an alluvium layer not considered in this report.
[b] Data table S99105_004 was excluded because the lithostratigraphy correlation data (DTN MO0004QGFMPICK.000 [DIRS 152554]) are not available for UE-25 NRG #3.
[c] Data table S99109_001 was excluded because the data are for the repository layers not considered in this report.

4.4.2 Thermal Conductivity

The sources of thermal conductivity data used to validate the thermal conductivity model are shown in Table 4-7.

Table 4-7. Sources of Thermal Conductivity Data

Data Source Description	Reference DTN	Data Table
Matrix thermal conductivity data for Boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, and USW NRG-7/7a	SNL01A05059301.005 [DIRS 109002]	S96370_001
Matrix thermal conductivity data for Boreholes USW SD-7, USW SD-9, and USW SD-12	SNL22100196001.006 [DIRS 158213]	S98169_002
Matrix thermal conductivity summary data	SN0011T0571897.014 [DIRS 154449]	S00441_001

Data tables DTN SNL01A05059301.005 [DIRS 109002] s96370_001 and DTN SNL22100196001.006 [DIRS 158213] s98169_002 were used to develop the thermal conductivity model. DTN SN0011T0571897.014 [DIRS 154449] data table s00441_001 and the data not used for model building in tables SNL01A05059301.005 [DIRS 109002] s96370_001 and DTN SNL22100196001.006 [DIRS 158213] s98169_002 are used to validate the model.

All ten qualified validation thermal conductivity values for the Prow Pass Tuff and all eight qualified validation thermal conductivity values available for the Bullfrog Tuff come from DTN SN0011T0571897.014 [DIRS 154449] data table s00441_001. Eight of the locations for these data, designated by Tcp1, Tcp2, Tcp3, Tcp4, Tcb1, Tcb2, Tcb3, and Tcb4, are not standard lithostratigraphic units as defined in Table U-1. The designations span one or more standard lithostratigraphic units. A correlation between these designations and stratigraphic units listed in Table U-1 was established by using borehole identifier and depth information in DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)) and examining the relative sizes of the thermal conductivity values in DTN SN0011T0571897.014 ([DIRS 154449] data table s00441_001).

The DTN MO0109HYMXPROP.001 [DIRS 155989] data table s01144_001 (file *DATAQ.zip*) includes 239 lines of data from Tcp units 1, 2, 3, and 4, each with borehole identifier and depth. The borehole identifiers and depths allow the unique determination of the stratigraphic units listed in Table U-1. Of the 114 values for Tcp unit 1, 105 were from Prow Pass Tuff non-welded units, and nine were from Bullfrog Tuff non-welded units, so Tcp1 is most likely categorized as Prow Pass non-welded, with a possibility of being Bullfrog non-welded. The Tcp1 data are assigned to the Prow Pass non-welded category, and the impact of the data actually falling in the Bullfrog non-welded category will be assessed at the end of this section (Section 4.4.2).

The 56 values for Tcp unit 2 in DTN MO0109HYMXPROP.001 [DIRS 155989] data table s01144_001 (file *DATAQ.zip*) correspond to stratigraphic unit Tcplv (see Table U-1), which is in the Prow Pass non-welded category. The two Tcp unit 4 points correspond to Tcpuv, which is Prow Pass non-welded; therefore, both Tcp2 and Tcp4 are Prow Pass non-welded layers.

The 67 values for Tcp unit 3 in DTN MO0109HYMXPROP.001 [DIRS 155989] data table s01144_001 (file *DATAQ.zip*) correspond to both welded and non-welded units. The dry thermal conductivity values for Tcp1, Tcp2, Tcp3, and Tcp4 in DTN SN0011T0571897.014 [DIRS 154449] data table s00441_001 are 0.67, 0.69, 0.63, and 0.60 watts per meter degree Kelvin (W/m K), respectively. Because the high and low values are non-welded (Tcp2 and Tcp4), it is reasonable that all four values are non-welded values.

The wet thermal conductivity values for Tcp1, Tcp2, Tcp3, and Tcp4 are 1.28, 1.32, 1.23, and 1.18 W/m K, respectively. Because the values for Tcp1 and Tcp2 samples fall within the range defined by Tcp2and Tcp4, it is reasonable to assign non-welded values to all four samples.

The Bullfrog designators Tcb1, Tcb2, Tcb3, and Tcb4 are not present in any input DTN other than SN0011T0571897.014 [DIRS 154449], so the assignment to welded or non-welded is based on the similarity to the Prow Pass data, and on the relative sizes of the thermal conductivity values. The dry thermal conductivity values for Tcb1, Tcb2, Tcb3, and Tcb4 are 0.70, 0.70, 1.40, and 1.40 W/m K, respectively. The 95-percent confidence limits on these values in the source DTN SN0011T0571897.014 [DIRS 154449] are 0.68 to 0.72 W/m K for Tcb1 and Tcb2 and 1.37 to 1.44 W/m K for Tcb3 and Tcb4. It is reasonable that the 0.70 W/m K values represent non-welded layers because of their closeness to the Prow Pass non-welded range of 0.60 to 0.69 W/m K. It is reasonable that the significantly higher 1.40 W/m K values represent the welded layers.

The wet thermal conductivity values for Tcb1, Tcb2, Tcb3, and Tcb4 are 1.33, 1.33, 1.85, and 1.85 W/m K, respectively. The 95-percent confidence limits are 1.20 to 1.46 W/m K for Tcb1 and Tcb2 and 1.80 to 1.90 W/m K for Tcb3 and Tcb4, so the values are from two distinctly different groups. It is reasonable that the 1.33 W/m K values are non-welded and the 1.85 W/m K values are welded because the welded thermal conductivities tend to be higher than the non-welded within a layer. The Tcp non-welded thermal conductivity averages are 0.648 W/m K for dry samples and 1.25 W/m K for wet samples. The Tcb non-welded averages are 0.70 W/m K for dry samples and 1.33 W/m K for wet samples. If the Tcp1 values were assigned to the Bullfrog unit rather than the Prow Pass unit, the new thermal conductivity averages would be 0.640 W/m K for dry Tcp, 1.24 W/m K for wet Tcp, 0.69 W/m K for dry Tcb and 1.31 W/m K for wet Tcb. The changes are all less than 1.6 percent. These changes would be negligible in the model validation because all the model standard deviations will be shown to exceed 10 percent of the means.

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5. ASSUMPTIONS

Assumption 1: Data from boreholes UE-25 NRG #4, USW NRG-6, USW NRG-7, USW SD-7, USW SD-9, and USW SD-12 intersect the repository and are representative of the repository layers in terms of matrix porosity, saturated thermal conductivity and dry thermal conductivity. These boreholes are also assumed to be representative of the entire Yucca Mountain.

Basis: The boreholes are well spaced and located in the interior of the repository boundary. They sample an appropriate portion of the repository host rock and surrounding lithostratigraphic units.

Confirmation Status: Confirmed. This assumption is verified by showing that the means for the model and the means for the remaining data are not statistically different at a confidence level of 95 or 98 percent. The assumption is validated in Section 7.1. No further confirmation is needed because Assumption 1 is fully supported by the statistical analysis in Section 7.1.

Use: Assumption 1 is used in selecting the data processed as described in Section 6.3 and Section 6.4.

Assumption 2: It is assumed that the vitric solid thermal conductivity distribution can be approximated by a uniform distribution over the thermal conductivity range for glass from the *Chemical Engineers' Handbook* (Perry and Chilton 1973 [DIRS 104946], p. 3-260), from 0.35 to 1.26 W/m K and the γ_c distribution is constant with value 1.0. (This value is the most probable value for the γ_c distributions above the Calico Hills.)

Basis: The chemical and mineral composition of vitric lithostratigraphic units associated with layers surrounding the repository are sufficiently similar to glass as characterized in the engineering handbook to enable this approximation of material properties to be valid for this use.

Confirmation Status: Confirmed. The assumption is validated in Section 7.3. No further confirmation is required because Assumption 2 is fully supported by the statistical analysis in Section 7.3. Justification of this assumption is provided by showing that the model mean and the mean of the remaining data are not statistically different at a confidence level of 95 or 98 percent.

Use: Assumption 2 is used in the data processed as described in Section 6.3 and Section 6.4.

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6. MODEL

As outlined in Section 1, this report documents the development and results of the thermal conductivity model for nonrepository layers of the Yucca Mountain. Section 6 consists of the following:

- Model discussion (Section 6.1)
- Uncertainties in data measurement (Section 6.2)
- Creation of matrix porosity, wet thermal conductivity, and dry thermal conductivity triads (Section 6.3)
- Distributions of gamma_c and solid thermal conductivity for welded, non-welded, vitric, and Calico rock types (Section 6.4)
- Distributions of matrix porosity for welded, non-welded, vitric, Calico, Prow, Bullfrog, and Tram Tuff units (Section 6.5)
- Distributions of matrix porosity, gamma_c and solid thermal conductivity used by GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) (Section 6.6)
- Dry bulk density analysis (Section 6.7)
- Impact of the choice of distribution type on thermal conductivity values (Section 6.8).

Data used for model development are listed according to the following direct input use:

Lithostratigraphic contact input data are from DTN MO0004QGFMPICK.000 [DIRS 152554] and DTN SNF40060298001.001 [DIRS 107372].

Layer characterization of model units is from Table U-1, DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001), DTN SNF40060298001.001 ([DIRS 107372 s98430_001), DTN SNL01A05059301.007 ([DIRS 108980] s98424_003), DTN SNL01A05059301.005 ([DIRS 109002] s96370_001), DTN MO0109HYMXPROP.001 ([DIRS 155989] s01144_001 (file *DATAQ.zip*)), and DTN SNL22100196001.006 ([DIRS 158213] s98169_002).

Matrix porosity input data are from DTN SNL01A05059301.007 ([DIRS 108980] s98424_003), DTN GS000508312231.006 ([DIRS 153237] s00415_001), DTN MO0109HYMXPROP.001 ([DIRS 155989] s01144_001 (FILE *DATAQ.ZIP*)), DTN SNL02030193001.002 ([DIRS 120575] s98484_001), DTN SNL02030193001.002 ([DIRS 120575] s98484_005), and DTN SNL02030193001.022 ([DIRS 109613] s99111_001).

Thermal conductivity input data are from DTN SNL01A05059301.005 ([DIRS 109002] s96370_001) and DTN SNL22100196001.006 ([DIRS 158213] s98169_002).

As discussed in Section 4.1.5, dry bulk density data were not used for model development. They were included in the model output (Table 6-13) only to correlate model units with average dry bulk density values. Appendix V documents the qualification of two unqualified data sets

(GS920408312314.011 [DIRS 129660] and GS930408312132.007 [DIRS 129625]) intended for use (product output) in this model report.

No corroborating or supporting data were used for model development.

6.1 MODEL DISCUSSION

The thermal conductivity model for nonrepository layers of the Yucca Mountain is a summary of wet and dry thermal conductivities for the GFM lithostratigraphic units based on qualified, verified thermal conductivity measurements.

The thermal conductivity of porous materials has been the subject of considerable study for several decades. Consequently, many analytical and empirical models have been developed for this property. This research is beneficial from the perspective of finding a predictive model that may be applied at Yucca Mountain. In order to include the effects of matrix porosity and saturation in the model, a mathematical model developed by Hsu et al. (1995 [DIRS 158073]) was used to represent the thermal conductivity of the repository horizons (*Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]). The nonrepository thermal conductivity model continues to use the Hsu model for the reasons cited in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 6.1.7).

As cited in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 6.1.7), three candidate models are examined for application at Yucca Mountain. The proposed models are “Heat Transfer Characteristics of Porous Rocks.” *American Institute of Chemical Engineers Journal, 6* (Kunii and Smith 1960 [DIRS 153166]); “Thermal Conductivity of Packed Metal Powders.” *International Journal of Heat and Mass Transfer, 29* (Hadley 1986 [DIRS 153165]); and “A Lumped-Parameter Model for Stagnant Thermal Conductivity of Spatially Periodic Porous Media.” *Journal of Heat Transfer, 117* (Hsu et al. 1995 [DIRS 158073]). All three models address consolidated porous media and in theory are good candidates for this work. One of the three was ultimately selected based on the following screening criteria:

1. The theoretical development must be well documented, relatively easy to comprehend, and appropriate for consolidated porous media.

2. The model must be capable of reproducing experimental results within the estimated range of experimental error.

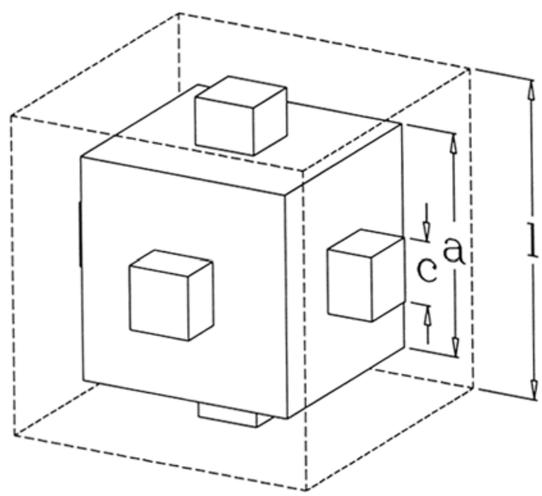
3. The model parameters and their uncertainty must be easily derived through existing qualified data.

Kunii and Smith (1960 [DIRS 153166]) assume that the thermal conductivity of a porous medium can be represented by a layer of fluid acting in parallel with a composite layer consisting of both fluid and solid phases. Parameters that dictate the geometry of the composite layer are derived based on an analytical solution of heat flow between two spheres. The authors extrapolate this solution to approximate multiple spheres by considering additional contact points and the orientation of these contacts for various packing arrangements. The theory can be extended to consolidated porous media by adjusting the shape and relative size of void and solid space.

The fundamental premise behind the Kunii and Smith model is that the analytical solution of heat flux between two spheres can be stretched and approximated to the point that it is applicable to consolidated porous substances. This argument is convincing for unconsolidated granular substances, but not as convincing for consolidated media, because the geometric configuration of the pore space in the latter is quite different for loosely packed spheres for which the basic formulation of the Kunii and Smith model was developed. This model was, therefore, not selected based on Criterion 1.

The Hadley model (1986 [DIRS 153165]) is derived from volume-averaging theory and makes use of the pioneering work of Maxwell (1954 [DIRS 158165], pp. 440 and 441). This is a versatile model that is applicable over the complete range of potential pore structures. In addition, the model is unique in that it is not explicitly tied to a specific geometry or packing arrangement. The model was not selected, however, due to the difficulty of quantifying model parameter uncertainty from existing data.

The final model examined and ultimately selected is the 3-D cubic model developed by Hsu et al. (1995 [DIRS 158073]). This model is conceptually similar to that proposed by Kunii and Smith (1960 [DIRS 153166]) in that a simplified geometrical representation of the porous medium is proposed and then the effective thermal conductivity of the simplified problem is derived through resistance analogues. In the case of the 3-D cubic model, the porous medium is represented by a periodic array of in-line cubes with connecting nodules. The unit cell of the 3-D periodic array is shown in Figure 6-1.



Source: Hsu et al. (1995 [DIRS 158073], Figure 8).

Figure 6-1. 3-D Schematic of the HSU Model

Hsu et al. (1995 [DIRS 158073], Equation 14) derive the following equation for this geometry:

$$\frac{k_m}{k_f} = 1 - \gamma_a^2 - 2\gamma_c\gamma_a + 2\gamma_c\gamma_a^2 + \frac{\gamma_c^2\gamma_a^2}{\lambda} + \frac{\gamma_a^2 - \gamma_c^2\gamma_a^2}{1 - \gamma_a + \gamma_a\lambda} + \frac{2\left(\gamma_c\gamma_a - \gamma_c\gamma_a^2\right)}{1 - \gamma_c\gamma_a + \gamma_c\gamma_a\lambda} \qquad \text{(Eq. 6-1)}$$

where:

$\gamma_a = a/l$; $\gamma_c = c/a$; $\lambda = k_f / k_s$;

and

k_s, k_f, and k_m are the thermal conductivities of the solid, fluid, and composite matrix, respectively,

and where:

the scales *a*, *c*, and *l* are as shown in Figure 6-1.

As illustrated in Figure 6-1, *l* is the length of the unit cell cube shown, *a* is the length of one side of the solid square, and *c* is the width of the connecting nodule. It should be noted that the connecting nodules have square cross-sections, but are not cubes. The connecting nodule protrudes from the face of the solid cube a distance defined by (*l*-*a*)/2.

For the 3-D cubic model unit cell illustrated in Figure 6-1, the pore-volume may be computed by subtracting the volume of the solid cube, a^3, and the 6 connecting nodules, each having a volume of $c^2(l-a)/2$, from the unit cell volume, l^3. Furthermore, from geometrical considerations it can be shown that γ_a and γ_c are functionally dependent. This dependency may be written as Hsu et al.'s Equation 13 (1995 [DIRS 158073]):

$$1 - \phi_m - \gamma_a^3 - 3\gamma_c^2\left(\gamma_a^2 - \gamma_a^3\right) = 0\,. \qquad \text{(Eq. 6-2)}$$

It is apparent from Equation 6-1 and Equation 6-2 that the effective matrix thermal conductivity may be expressed as a function of four independent variables:

$$k_m = f\left(k_f, k_s, \phi_m, \gamma_c\right). \qquad \text{(Eq. 6-3)}$$

The Hsu model uses parameters matrix porosity (ϕ_m), solid thermal conductivity (k_s), a geometrical factor (γ_c), and thermal conductivities for air and water to generate the wet and dry matrix thermal conductivities (k_w and k_d) of a material. The geometrical factor is not a measurable quantity, and measurements of solid thermal conductivity usually are not available, but both can be calculated using the inverse of the Hsu model. The inverse code HSUINV (STN 10804-1.0-00 [DIRS 158228]), takes matrix porosity and wet (saturated) and dry thermal conductivity measurements and calculates k_s and γ_c. This computational method was chosen over other inverse codes because the HSUINV (STN 10804-1.0-00 [DIRS 158228]) software is used for a parallel modeling study involving potential repository layers (BSC 2004 [DIRS 169854]). The model development is done using qualified, verified data for matrix porosity and thermal conductivity for boreholes USW SD-7, USW SD-9, USW SD-12, UE-25

NRG #4, UE-25 NRG #5, USW NRG-6, and USW NRG-7/7a. These inputs are identified in Table 4-3 and Table 4-4.

From the calculated values of k_s and γ_c, distributions of k_s and γ_c are developed with methods discussed in Section 6.4 for four categories of geologic layers (defined in Section 4.1.1):

1. Welded
2. Non-welded
3. Vitric
4. Calico.

Because there are many more matrix porosity values than thermal conductivity values, matrix porosity distributions are developed with methods discussed in Section 6.5 for 10 types of geologic layers:

1. Welded above the Calico Hills
2. Non-welded above the Calico Hills
3. Vitric
4. Calico Hills
5. Prow Pass welded
6. Prow Pass non-welded
7. Bullfrog welded
8. Bullfrog non-welded
9. Tram Tuff welded
10. Tram Tuff non-welded.

Combining the porosity and thermal conductivity distributions using qualified software package GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) gives the thermal conductivity model for these ten types. The model is presented as the mean and standard deviation for k_d, k_w, and ϕ_m for each of the 41 nonrepository model units (see Table U-1) within the ten types of geologic layers.

The model development is done using most of the qualified, verified data for matrix porosity and thermal conductivity for boreholes USW SD-7, USW SD-9, USW SD-12, UE-25 NRG #4, UE-5 NRG #5, USW NRG-6, and USW NRG-7. These inputs are identified in Table 4-3 and Table 4-4. All of the remaining qualified, verified data for matrix porosity and thermal conductivity are used for data for model validation. These inputs are identified in Table 4-6 and Table 4-7.

The Product Output information from this model report is available in the TDMS as DTN SN0307T0503102.009. The top-level directory contains a file *README.TXT* that describes how to reproduce the calculations and output in this report. There are two first level subdirectories: Inputs and Outputs. Subdirectory Inputs contains subdirectories Genhsumodeldata, Hsuinv, Lithostr, QVDryBulkDens, QVPorosity, and QVTC. Subdirectory Outputs contain subdirectories HsuInv, Lithostr, QVDryBulkDens, QVPorosity, QVTC, TCRegression, and Validation. Subdirectories Inputs and Outputs contain the input and output data described in Section 6 and Section 7 of this report. No preliminary outputs were developed for this study; therefore, comparison between preliminary and final output is not discussed.

The SEP data tables used in this report contain more than 35,000 lines of data, so the contents of the tables are not listed in this report. The SEP tables are included in subdirectories Inputs\Lithostr, Inputs\QVDryBulkDens, Inputs\QVPorosity and Inputs\QVTC with file names given by the data table name (shown in Table 4-3 to Table 4-7) with a .txt suffix appended.

6.2 UNCERTAINTIES IN DATA MEASUREMENT

Estimates on the uncertainties in the experimental measurements of porosity, bulk density, and wet and dry thermal conductivity are discussed in Appendix A. Although the term "errors" is used in Appendix A, these are actually uncertainties caused by limitations in the measuring equipment and technique rather than errors made by the person making the measurement. The matrix thermal conductivity measurement uncertainties are approximately 5 percent of the measured value for both oven dry and saturated specimens.

Differences between matrix porosities calculated using dry densities and grain densities, rather than dry bulk densities and saturated bulk densities, indicate relative differences as large as 17 percent; however a 9-percent relative difference is assessed to be a reasonable bound for most of the data (34 of 37 data points) (Appendix A, Column O of spreadsheet). Using these data (Appendix A, Column O), a reasonable estimate of measurement uncertainty is approximately 5 percent for porosities less than 0.11. However, the smallest porosity examined in Appendix A, Column L, is approximately 0.066. Therefore, the maximum relative uncertainty based on the absolute measurement uncertainty (1 percent in Appendix A) is approximately 15 percent (0.01/0.066 = 0.15) for values less than 0.11. For porosities greater than 0.11, 9 percent of the measured is a good bound on the measurement relative uncertainty, because 34 of 37 data points (approximately 92 percent of the data points) have smaller relative uncertainties.

Dry bulk density is computed from the specimen mass divided by the specimen volume. Mass is measured to 0.01g (Appendix A of this report) and masses are typically from 16 g to 60 g (DTN SNL01A05059301.002 [DIRS 150042], data table s99435_001), so the relative uncertainty in the mass measurement is, at most, 0.0006. Volumes are typically 12 cm^3 to 26 cm^3 (DTN SNL01A05059301.002 [DIRS 150042], data table s99435_001). Using the cube root of the volume as an estimate of the length measurement, the length measurement would be roughly 2.3 cm. Because lengths are usually accurate to 0.001 inch (approximately 0.0025 cm), the relative uncertainty in the length is approximately 0.001. Because the volume is approximately three times the length, the relative uncertainty in volume is approximately 0.003. Combining the measurement relative uncertainties in mass and volume, the relative uncertainty in the dry bulk density measurement is approximately 0.004, or approximately 0.4 percent. When measurement uncertainties are compared to model uncertainties in Section 6.6, they are bounded by the model uncertainties.

6.3 CREATION OF POROSITY, WET THERMAL CONDUCTIVITY, AND DRY THERMAL CONDUCTIVITY TRIADS

DTN SNL01A05059301.007 ([DIRS 108980] SEP table s98424_003) provides porosities for 54 samples. DTN SNL01A05059301.005 ([DIRS 109002] SEP table s96370_001) provides wet and dry thermal conductivity values at 56 different locations. The program SPLICE (STN 10906-1.0-00 [DIRS 162672]), which combines a file of porosity data with a file of wet and dry thermal conductivity data based on a common sample ID, uses these input data with the input control file shown in Appendix B to produce the 47 ϕ_m, k_d, k_w, data triads shown in Table 6-1. Table 6-1 is used as input to the inverse program HSUINV (STN: 10804-1.0-00 [DIRS 158228]) to obtain values for Hsu-model (Hsu et al. 1995 [DIRS 158073]) parameters k_s and γ_c. The output of the inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) is shown in Table 6-2; units of thermal conductivity (ks) are W/m K, and porosity (phi) and gamma_c (a geometrical factor (gc)) are dimensionless.

Table 6-1. Input Data from NRG Boreholes

Borehole Sample ID[a]	Porosity (ϕ_m)	Dry Thermal[b] Conductivity (k_d) (W/m K)	Wet Thermal[b] Conductivity (k_w) (W/m K)	Porosity Data Table Name (see Table 4-3)	Porosity Data Table Row	Thermal Conductivity Data Table Name (see Table 4-4)
NRG4 470.0 SNL B	0.4855043	0.355	0.980	s98424_003	3	s96370_001
NRG4 529.0 SNL B	0.1650256	1.160	1.670	s98424_003	4	s96370_001
NRG4 586.2 SNL B	0.1944229	0.945	1.640	s98424_003	6	s96370_001
NRG4 654.0 SNL B	0.1369164	1.155	1.800	s98424_003	10	s96370_001
NRG5 781.8 SNL A	0.1571485	1.000	1.920	s98424_003	11	s96370_001
NRG5 791.6 SNL A	0.2458759	0.820	1.780	s98424_003	12	s96370_001
NRG5 834.8 SNL B	0.0891167	1.655	1.920	s98424_003	13	s96370_001
NRG5 843.5 SNL A	0.0876777	1.650	2.200	s98424_003	14	s96370_001
NRG5 848.0 SNL B	0.1210091	1.500	2.610	s98424_003	15	s96370_001
NRG5 853.8 SNL A[c]	0.0873173	1.705	2.260	s98424_003	16	s96370_001
NRG5 874.9 SNL B[c]	0.0862342	1.675	2.320	s98424_003	17	s96370_001
NRG5 879.6 SNL A	0.0869565	1.625	3.090	s98424_003	18	s96370_001
NRG5 886.5 SNL B	0.1235689	1.370	2.530	s98424_003	19	s96370_001
NRG5 893.3 SNL B	0.1125198	1.460	2.750	s98424_003	20	s96370_001
NRG5 899.8 SNL B	0.1100516	1.475	2.770	s98424_003	21	s96370_001
NRG6 28.8 SNL C	0.0400000	1.750	1.910	s98424_003	22	s96370_001
NRG6 98.1 SNL I	0.0600000	1.590	1.710	s98424_003	23	s96370_001
NRG6 111.0 SNL I	0.0900000	1.435	2.010	s98424_003	24	s96370_001
NRG6 152.9 SNL E	0.4300000	0.430	1.040	s98424_003	25	s96370_001
NRG6 187.0 SNL F	0.4900000	0.315	0.790	s98424_003	26	s96370_001
NRG6 241.5 SNL E	0.6100000	0.250	0.730	s98424_003	27	s96370_001
NRG6 277.5 SNL E	0.1000000	1.255	1.680	s98424_003	28	s96370_001
NRG6 321.1 SNL E	0.1500000	1.165	1.710	s98424_003	29	s96370_001
NRG6 392.1 SNL D	0.0400000	1.185	1.550	s98424_003	31	s96370_001
NRG6 416.0 SNL K	0.0900000	1.285	1.550	s98424_003	32	s96370_001
NRG6 421.8 SNL D	0.1268657	1.190	1.700	s98424_003	33	s96370_001
NRG6 425.3 SNL B	0.1379992	1.260	1.820	s98424_003	34	s96370_001
NRG6 451.2 SNL B	0.1852146	1.290	1.700	s98424_003	35	s96370_001
NRG6 556.1 SNL B	0.2774451	0.910	2.040	s98424_003	36	s96370_001

Table 6-1. Input Data from NRG Boreholes (Continued)

Borehole Sample ID[a]	Porosity	Dry Thermal[b] Conductivity (W/m K)	Wet Thermal[b] Conductivity (W/m K)	Porosity Data Table Name (see Table 4-3)	Porosity Data Table Row	Thermal Conductivity Data Table Name (see Table 4-4)
NRG6 693.1 SNL C	0.1362916	1.385	1.930	s98424_003	37	s96370_001
NRG6 757.0 SNL B	0.0959556	1.610	2.020	s98424_003	38	s96370_001
NRG6 778.1 SNL B	0.0840000	1.710	1.850	s98424_003	39	s96370_001
NRG6 787.5 SNL B	0.1122611	1.600	1.720	s98424_003	40	s96370_001
NRG6 802.7 SNL D	0.0945353	1.670	1.780	s98424_003	41	s96370_001
NRG6 809.4 SNL B	0.0919952	1.640	1.660	s98424_003	42	s96370_001
NRG6 900.4 SNL D	0.1445313	1.500	2.230	s98424_003	43	s96370_001
NRG6 926.3 SNL E	0.1287437	1.540	2.150	s98424_003	44	s96370_001
NRG6 987.0 SNL B	0.1175322	1.550	2.040	s98424_003	45	s96370_001
NRG7 18.6 SNL D	0.0702314	1.550	1.900	s98424_003	46	s96370_001
NRG7 27.0 SNL B	0.0657578	1.480	1.930	s98424_003	47	s96370_001
NRG7 56.8 SNL D	0.1713371	1.175	2.040	s98424_003	48	s96370_001
NRG7 75.0 SNL D	0.3025142	0.745	1.200	s98424_003	49	s96370_001
NRG7 91.6 SNL D	0.4226626	0.435	1.010	s98424_003	50	s96370_001
NRG7 104.1 SNL C	0.5843724	0.320	0.950	s98424_003	51	s96370_001
NRG7 113.1 SNL B	0.4021739	0.435	1.040	s98424_003	52	s96370_001
NRG7 248.5 SNL D	0.4950367	0.345	0.980	s98424_003	53	s96370_001
NRG7 312.8 SNL D	0.1061018	1.330	1.630	s98424_003	54	s96370_001

NOTES: This table was generated by SPLICE (STN: 10906-1.0-00 [DIRS 162672]) using data from DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003) and from DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001).

The column headings have been modified for clarification and are not the same as in the computer output.

This output is included in Product Output DTN SN0307T0503102.009 file *Inputs\Hsuinv\nrghsuinv.inp*.

[a] Numeric values listed in the Sample ID column represent depth from the surface, in feet. The alpha character shown in the Sample ID column designates a particular test specimen taken from a single interval of core. When possible, wet and dry measurements were conducted on the same specimen.

[b] Wet and dry thermal conductivity values corresponding to 70°C and 110°C, respectively, were selected for input, based on abundance of data.

[c] Depths listed in the two input files disagree for NRG5 samples extracted from 853.8 feet and 874.9 feet because SPLICE (STN: 10906-1.0-00 [DIRS 162672]) allows for a difference of ±1.3 feet.

Table 6-2. HSUINV Output for Boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6 and USW NRG-7/7a

Porosity phi	Solid Thermal Conductivity (W/m K) ks	Gamma_c gc	Borehole Sample ID
0.486	1.471	0.683	NRG4 470.0 SNL B
0.165	2.048	0.943	NRG4 529.0 SNL B
0.194	2.101	0.753	NRG4 586.2 SNL B
0.137	2.165	0.799	NRG4 654.0 SNL B
0.157	2.419	0.663	NRG5 781.8 SNL A
0.246	2.569	0.617	NRG5 791.6 SNL A
0.089	2.419	1.000	NRG5 834.8 SNL B
0.088	2.533	0.888	NRG5 843.5 SNL A
0.122	3.299	0.693	NRG5 848.0 SNL B
0.088	2.610	0.892	NRG5 853.8 SNL A
0.087	2.687	0.845	NRG5 874.9 SNL B
0.087	3.739	0.632	NRG5 879.6 SNL A
0.124	3.193	0.662	NRG5 886.5 SNL B
0.113	3.451	0.647	NRG5 893.3 SNL B
0.110	3.462	0.647	NRG5 899.8 SNL B
0.040	2.203	1.000	NRG6 28.8 SNL C
0.060	2.134	1.000	NRG6 98.1 SNL I
0.090	2.296	0.849	NRG6 111.0 SNL I
0.430	1.507	0.730	NRG6 152.9 SNL E
0.490	1.093	1.000	NRG6 187.0 SNL F
0.610	1.197	1.000	NRG6 241.5 SNL E
0.100	1.894	0.945	NRG6 277.5 SNL E
0.150	2.070	0.874	NRG6 321.1 SNL E
0.040	1.617	0.843	NRG6 392.1 SNL D
0.090	1.869	1.000	NRG6 416.0 SNL K
0.127	1.991	0.884	NRG6 421.8 SNL D
0.138	2.194	0.870	NRG6 425.3 SNL B
0.185	2.375	1.000	NRG6 451.2 SNL B
0.277	3.366	0.578	NRG6 556.1 SNL B
0.136	2.345	0.906	NRG6 693.1 SNL C
0.096	2.395	1.000	NRG6 757.0 SNL B
0.084	2.466	1.000	NRG6 778.1 SNL B
0.112	2.484	1.000	NRG6 787.5 SNL B
0.095	2.478	1.000	NRG6 802.7 SNL D
0.092	2.415	1.000	NRG6 809.4 SNL B
0.145	2.842	0.814	NRG6 900.4 SNL D
0.129	2.639	0.873	NRG6 926.3 SNL E
0.118	2.437	1.000	NRG6 987.0 SNL B
0.0658	2.116	0.897	NRG7 27.0 SNL B

Table 6-2. HSUINV Output for Boreholes UE-25 NRG #4, UE-25 NRG #5, USW NRG-6 and USW NRG-7/7a (Continued)

Porosity phi	Solid Thermal Conductivity (W/m K) ks	Gamma_c gc	Borehole Sample ID
0.171	2.677	0.720	NRG7 56.8 SNL D
0.303	1.753	1.000	NRG7 75.0 SNL D
0.423	1.414	0.789	NRG7 91.6 SNL D
0.5843	1.648	0.706	NRG7 104.1 SNL C
0.4023	1.450	0.721	NRG7 113.1 SNL B
0.4953	1.496	0.665	NRG7 248.5 SNL D
0.106	2.021	1.000	NRG7 312.8 SNL D

NOTES: This table was generated by HSUINV (STN: 10804-1.0-00 [DIRS 158228]) using data from: DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003) and DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001).

The column headings have been modified for clarification, and are not the same as in the computer output.

This output is included in Product Output DTN SN0307T0503102.009 (file *Output\Hsuinv\\hsuinv\nrghsuinv.out*).

Data triads for the Calico Hills layer were created in the following manner. SEP data table DTN SNL22100196001.006 ([DIRS 158213] S98169_002) contains thermal conductivity and saturation values for boreholes USW SD-7, USW SD-9, and USW SD-12. SEP data table DTN MO0109HYMXPROP.001 ([DIRS 155989] s01144_001 (file *DATAQ.zip*)) contains porosity data for six samples for these boreholes in the Calico Hills Formation. These two data files are not in the format expected by the program SPLICE (STN 10906-1.0-00 [DIRS 162672]), so it is necessary to reformat the files using the program REFORMAT (STN 10907-2.0-00 [DIRS 162673]). The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control files are shown in Appendix C and Appendix D. The reformatted data tables *r01144_001.txt* (from DTN MO0109HYMXPROP.001 [DIRS 155989] data table s01144_001 (file *DATAQ.zip*)) and *r98169_002.txt* (from DTN SNL22100196001.006 [DIRS 158213] data table s98169_002) are used as input to the program SPLICE (STN 10906-1.0-00 [DIRS 162672]). The input control file for SPLICE (STN 10906-1.0-00 [DIRS 162672]) is shown in Appendix E. Table 6-3 shows the five data triads developed for the Calico Hills layer. Table 6-3 is used as input to the inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) to obtain values for Hsu-model parameters k_s and γ_c. The output of the inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) is shown in Table 6-4. Units of thermal conductivity are W/m K. Porosity and γ_c are dimensionless. Note that though data triads were not available for the Calico Hills layer, the process that creates the triads is reasonable because (1) the vertical depths at the sampling locations for the two data sets within the three different boreholes have comparable high porosities (25 to 35 percent) and (2) the degree of spatial correlation of the high porosity zones of the Calico Hills unit is of the order of several meters.

Therefore, it is reasonable to treat the sampling points between the data sets as the same.

The program REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) is used to append the lithostratigraphy to the two inverse-program HSUINV (STN 10804-1.0-00 [DIRS 158228]) output-data files. The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file is shown in Appendix F. The inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) output data with lithostratigraphy is shown in Table 6-5. The lithostratigraphic units Tptpmn, Tptpul, and Tptpll are repository layers and are not used in this model.

Table 6-3. HSUINV Input for Boreholes USW SD-7, USW SD-9, and USW SD-12

Borehole Sample ID	Porosity	Dry Thermal Conductivity[a] (W/m K)	Wet Thermal Conductivity[b] (W/m K)	Porosity (see Table 4-3)	
				Data Table Name	Data Table Row
SD7 1509	0.325	0.535	1.100	s01144_001	2211
SD9 1635.1	0.356	0.520	1.220	s01144_001	2978
SD9 1813.2	0.248	0.730	1.580	s01144_001	3035
SD12 1513.0	0.381	0.530	1.150	s01144_001	3545
SD12 1644.9	0.260	0.760	1.420	s01144_001	3587

NOTES: This table was generated by SPLICE (STN 10906-1.0-00 [DIRS 162672]) using data from DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file DATAQ.zip)) and DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The column headings have been modified for clarification and are not the same as in the computer output.

This output is included in Product Output DTN SN0307T0503102.009.

[a]At 110°C.
[b]At 70°C.

Table 6-4. HSUINV Output for Boreholes USW SD-7, USW SD-9, and USW SD-12

Porosity phi	Solid Thermal Conductivity (W/m K) ks	Gamma_c gc	Borehole Sample ID
0.325	1.437	0.781	SD7 1509
0.356	1.766	0.658	SD9 1635.1
0.248	2.180	0.634	SD9 1813.2
0.381	1.661	0.750	SD12 1513.0
0.260	1.909	0.749	SD12 1644.9

NOTES: This table was generated by HSUINV (STN: 10804-1.0-00 [DIRS 158228]) using data from DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file DATAQ.zip)) and DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The column headings have been modified for clarification and are not the same as in the computer output.

This output is included in Product Output DTN SN0307T0503102.009.

Table 6-5. HSUINV Output File with Lithostratigraphy

phi	ks (W/m K)	gc	Borehole Sample ID	Lithostratigraphic Unit
0.486	1.471	0.683	NRG4 470.0 SNL B	Tpbt2
0.165	2.048	0.943	NRG4 529.0 SNL B	Tptrn
0.194	2.101	0.753	NRG4 586.2 SNL B	Tptrn
0.137	2.165	0.799	NRG4 654.0 SNL B	Tptrn
0.157	2.419	0.663	NRG5 781.8 SNL A	Tptpmn
0.246	2.569	0.617	NRG5 791.6 SNL A	Tptpmn
0.089	2.419	1.000	NRG5 834.8 SNL B	Tptpmn
0.088	2.533	0.888	NRG5 843.5 SNL A	Tptpmn
0.121	3.299	0.693	NRG5 848.0 SNL B	Tptpmn
0.087	2.610	0.892	NRG5 853.8 SNL A	Tptpmn
0.086	2.687	0.845	NRG5 874.9 SNL B	Tptpmn
0.087	3.739	0.632	NRG5 879.6 SNL A	Tptpmn
0.124	3.193	0.662	NRG5 886.5 SNL B	Tptpmn
0.113	3.450	0.647	NRG5 893.3 SNL B	Tptpmn
0.110	3.462	0.647	NRG5 899.8 SNL B	Tptpmn
0.040	2.203	1.000	NRG6 28.8 SNL C	Tpc_un
0.060	2.136	1.000	NRG6 98.1 SNL I	Tpc_un
0.090	2.296	0.849	NRG6 111.0 SNL I	Tpc_un
0.430	1.508	0.730	NRG6 152.9 SNL E	Tpcpv1
0.490	1.093	1.000	NRG6 187.0 SNL F	Tpp
0.610	1.197	1.000	NRG6 241.5 SNL E	Tpbt2
0.100	1.894	0.945	NRG6 277.5 SNL E	Tptrn
0.150	2.070	0.874	NRG6 321.1 SNL E	Tptrn
0.040	1.617	0.843	NRG6 392.1 SNL D	Tptrn
0.090	1.869	1.000	NRG6 416.0 SNL K	Tptrn
0.127	1.991	0.884	NRG6 421.8 SNL D	Tptrn
0.138	2.194	0.870	NRG6 425.3 SNL B	Tptrn
0.185	2.375	1.000	NRG6 451.2 SNL B	Tptrl
0.277	3.366	0.578	NRG6 556.1 SNL B	Tptpul
0.136	2.345	0.906	NRG6 693.1 SNL C	Tptpul
0.096	2.395	1.000	NRG6 757.0 SNL B	Tptpmn
0.084	2.466	1.000	NRG6 778.1 SNL B	Tptpmn
0.112	2.484	1.000	NRG6 787.5 SNL B	Tptpmn
0.095	2.478	1.000	NRG6 802.7 SNL D	Tptpmn
0.092	2.415	1.000	NRG6 809.4 SNL B	Tptpmn
0.145	2.842	0.814	NRG6 900.4 SNL D	Tptpll
0.129	2.640	0.873	NRG6 926.3 SNL E	Tptpll
0.118	2.437	1.000	NRG6 987.0 SNL B	Tptpll
0.070	2.144	1.000	NRG7 18.6 SNL D	Tpc_un
0.066	2.116	0.897	NRG7 27.0 SNL B	Tpc_un
0.171	2.677	0.720	NRG7 56.8 SNL D	Tpc_un
0.303	1.753	1.000	NRG7 75.0 SNL D	Tpcpv2
0.423	1.414	0.789	NRG7 91.6 SNL D	Tpcpv1

Table 6-5. HSUINV Output File with Lithostratigraphy (Continued)

phi	ks (W/m K)	gc	Borehole Sample ID	Lithostratigraphic Unit
0.584	1.648	0.706	NRG7 104.1 SNL C	Tpbt4
0.402	1.450	0.721	NRG7 113.1 SNL B	Tpy
0.495	1.496	0.665	NRG7 248.5 SNL D	Tpp
0.106	2.021	1.000	NRG7 312.8 SNL D	Tptrn
0.325	1.437	0.781	SD7 1509	Tac
0.356	1.766	0.658	SD9 1635.1	Tac
0.248	2.180	0.634	SD9 1813.2	Tacbt
0.381	1.661	0.750	SD12 1513.0	Tac
0.260	1.909	0.749	SD12 1644.9	Tacbt

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001), DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001), DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003), DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001), DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and from DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

Lithostratigraphic units are designations of GFM2000 (Appendix U).

6.4 DISTRIBUTIONS OF GAMMA_C AND SOLID THERMAL CONDUCTIVITY FOR WELDED, NON-WELDED, VITRIC, AND CALICO ROCK TYPES

Just as the thermal conductivity of a material will vary spatially, the k_s and γ_c values generated from experimental data tend to differ for each triad. Instead of using a constant or mean value for each parameter, the calculated values are used to approximate probability distributions for the parameter. The program GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) samples these probability distributions for ϕ_m, k_s, and γ_c and calculates averages and standard deviations for ϕ_m, k_d, and k_w. However, the only distribution types accepted by GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) are normal, uniform, and exponential.

For some of the available data, the γ_c distribution appears roughly exponential, with its peak probability at $\gamma_c = 1$ (the theoretical range of γ_c is from 0, exclusive, to 1, inclusive). For some geologic layers the distribution is not readily identifiable because there are too few measurements available. A uniform distribution is used when the data are not readily identifiable as a particular type of probability distribution. The impact of choosing a uniform distribution when a normal distribution might be considered more appropriate is assessed in Section 6.8. The impact was found to be negligible. In a similar manner, a probability distribution can be assigned to the values of k_s that are calculated by the inverse program HSUINV (STN: 10804-1.0-00 [DIRS 158228]). The same could be done with matrix porosity, but because there are more than 1,700 matrix porosity measurements and only 31 data triads of matrix porosity and wet and dry thermal conductivity, it is more reasonable to take the larger number of data points and determine the matrix porosity distribution from them.

The program REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) is used to separate the inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) output file with lithostratigraphy into four k_s files and four γ_c files based on the lithostratigraphy. The vitric output files contain headers, but no data. The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file is shown in Appendix G. Data from the separate data tables are shown in Table 6-6 to Table 6-11. The first line of these tables shows the geologic layers for the data. The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]). The third line is the x-axis label for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

Data triads corresponding to the repository have been removed at this point by REFORMAT (STN 10907-2.0-00 [DIRS 162673])

Table 6-6. Welded Solid Thermal Conductivity Data

Welded Layers		
1		
Solid Thermal Conductivity (W/m K)	**Lithostratigraphic Unit**	**Borehole Sample ID**
2.048	Tptrn	NRG4 529.0 SNL B
2.101	Tptrn	NRG4 586.2 SNL B
2.165	Tptrn	NRG4 654.0 SNL B
2.203	Tpc_un	NRG6 28.8 SNL C
2.134	Tpc_un	NRG6 98.1 SNL I
2.296	Tpc_un	NRG6 111.0 SNL I
1.894	Tptrn	NRG6 277.5 SNL E
2.070	Tptrn	NRG6 321.1 SNL E
1.617	Tptrn	NRG6 392.1 SNL D
1.869	Tptrn	NRG6 416.0 SNL K
1.991	Tptrn	NRG6 421.8 SNL D
2.194	Tptrn	NRG6 425.3 SNL B
2.375	Tptrl	NRG6 451.2 SNL B
2.144	Tpc_un	NRG7 18.6 SNL D
2.116	Tpc_un	NRG7 27.0 SNL B
2.677	Tpc_un	NRG7 56.8 SNL D
2.021	Tptrn	NRG7 312.8 SNL D

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The first line of this table shows the geologic layers for the data.

The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The third line is the x-axis label for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

Table 6-7. Welded Gamma_c Data

Welded Layers		
1		
Gamma_c	**Lithostratigraphic Unit**	**Borehole Sample ID**
0.943	Tptrn	NRG4 529.0 SNL B
0.753	Tptrn	NRG4 586.2 SNL B
0.799	Tptrn	NRG4 654.0 SNL B
1.000	Tpc_un	NRG6 28.8 SNL C
1.000	Tpc_un	NRG6 98.1 SNL I
0.849	Tpc_un	NRG6 111.0 SNL I
0.945	Tptrn	NRG6 277.5 SNL E
0.874	Tptrn	NRG6 321.1 SNL E
0.843	Tptrn	NRG6 392.1 SNL D
1.000	Tptrn	NRG6 416.0 SNL K
0.884	Tptrn	NRG6 421.8 SNL D
0.870	Tptrn	NRG6 425.3 SNL B
1.000	Tptrl	NRG6 451.2 SNL B
1.000	Tpc_un	NRG7 18.6 SNL D
0.897	Tpc_un	NRG7 27.0 SNL B
0.720	Tpc_un	NRG7 56.8 SNL D
1.000	Tptrn	NRG7 312.8 SNL D

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file DATAQ.zip)), and
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The first line of this table shows the geologic layers for the data.

The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The third line is the x-axis label for HISTPLT(STN 10802-2.01-00 [DIRS 158223]).

Table 6-8. Non-welded Solid Thermal Conductivity Data

Non-welded Layers		
1		
Solid thermal conductivity (W/m K)	**Lithostratigraphic Unit**	**Borehole Sample ID**
1.471	Tpbt2	NRG4 470.0 SNL B
1.507	Tpcpv1	NRG6 152.9 SNL E
1.093	Tpp	NRG6 187.0 SNL F
1.197	Tpbt2	NRG6 241.5 SNL E
1.753	Tpcpv2	NRG7 75.0 SNL D
1.414	Tpcpv1	NRG7 91.6 SNL D
1.648	Tpbt4	NRG7 104.1 SNL C
1.450	Tpy	NRG7 113.1 SNL B
1.496	Tpp	NRG7 248.5 SNL D

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001), DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001), DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003), DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001), DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and DTN: SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The first line of this table shows the geologic layers for the data.

The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The third line is the x-axis label for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

Table 6-9. Non-welded Gamma_c Data

Non-welded Layers		
1		
Gamma_c	**Lithostratigraphic Unit**	**Borehole Sample ID**
0.683	Tpbt2	NRG4 470.0 SNL B
0.730	Tpcpv1	NRG6 152.9 SNL E
1.000	Tpp	NRG6 187.0 SNL F
1.000	Tpbt2	NRG6 241.5 SNL E
1.000	Tpcpv2	NRG7 75.0 SNL D
0.789	Tpcpv1	NRG7 91.6 SNL D
0.706	Tpbt4	NRG7 104.1 SNL C
0.721	Tpy	NRG7 113.1 SNL B
0.665	Tpp	NRG7 248.5 SNL D

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The first line of this table shows the geologic layers for the data.

The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The third line is the x-axis label for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

Table 6-10. Calico Hills Solid Thermal Conductivity Data

Calico Hills Layers		
1		
Solid thermal conductivity (W/m K)	**Lithostratigraphic Unit**	**Borehole Sample ID**
1.437	Tac	SD7 1509
1.766	Tac	SD9 1635.1
2.180	Tacbt	SD9 1813.2
1.661	Tac	SD12 1513.0
1.909	Tacbt	SD12 1644.9

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The first line of this table shows the geologic layers for the data.

The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The third line is the x-axis label for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

Table 6-11. Calico Hills Gamma_c Data

Calico Hills Layers		
1		
Gamma_c	**Lithostratigraphic Unit**	**Borehole Sample ID**
0.781	Tac	SD7 1509
0.658	Tac	SD9 1635.1
0.634	Tacbt	SD9 1813.2
0.750	Tac	SD12 1513.0
0.749	Tacbt	SD12 1644.9

NOTES: This table was generated by REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) using data from
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), and
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002).

The first line of this table shows the geologic layers for the data.

The “1” on the second line specifies that column one contains input data for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The third line is the x-axis label for HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

The welded k_s values are shown in the histogram produced by HISTPLT (STN 10802-2.01-00 [DIRS 158223]) in Figure 6-2. By visual inspection, a normal probability density distribution appears appropriate for a distribution, partly because the peak probability occurs near the center of the distribution, but also because the density of points drops off away from the center. The welded γ_c values are shown in the histogram in Figure 6-3. By visual inspection, an exponential distribution increasing between zero and one appears appropriate for the distribution.

The program GENHSUMODELDATA (STN: 10905-1.0-00 [DIRS 162671]) requires as input the growth or decay rate of an exponential distribution. The growth or decay rate λ can be found by iteration from the equation for the mean μ:

$$\mu = \frac{(1 - 1/\lambda)e^{\lambda} + 1/\lambda}{(e^{\lambda} - 1)} \qquad \text{(Eq. 6-4)}$$

For increasing exponentials with μ greater than 0.6, a good starting guess for λ is:

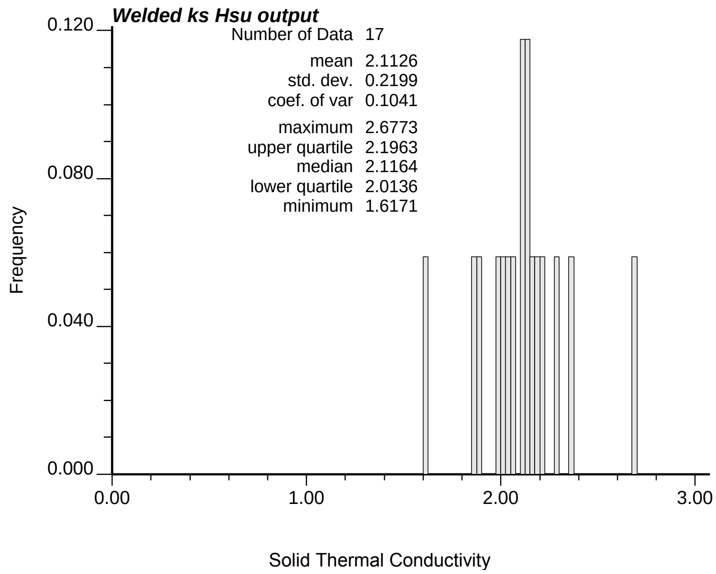
$$\lambda = 1/(1 - \mu) \qquad \text{(Eq. 6-5)}$$

For decreasing exponentials with μ less than 0.3, a good starting guess for λ is:

$$\lambda = -\,1/\mu \qquad \text{(Eq. 6-6)}$$

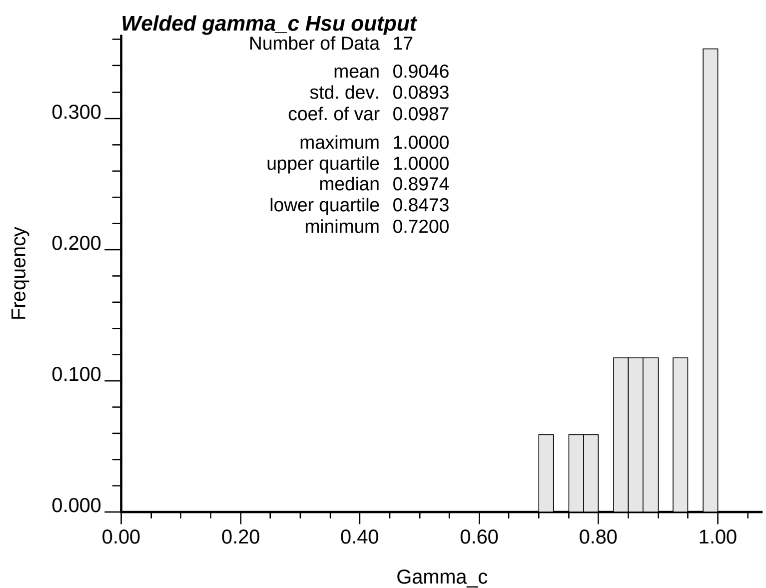
This starting guess is likely to be accurate to two or more significant digits. Appendix H contains a derivation of Equation 6-4, Equation 6-5, and Equation 6-6, and examples of the use of tabulations to improve the approximation of λ.

For the welded γ_c mean 0.9046, the growth rate λ is 10.479.



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-2. Welded Solid Thermal Conductivity Histogram



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-3. Welded Gamma_c Histogram

The non-welded k_s values are shown in the histogram in Figure 6-4. The standard deviations shown in the histograms from the program HISTPLT (STN 10802-2.01-00 [DIRS 158223]) compute the standard deviation using a division by sqrt(N), where N is the number of points to obtain the appropriate standard deviation.

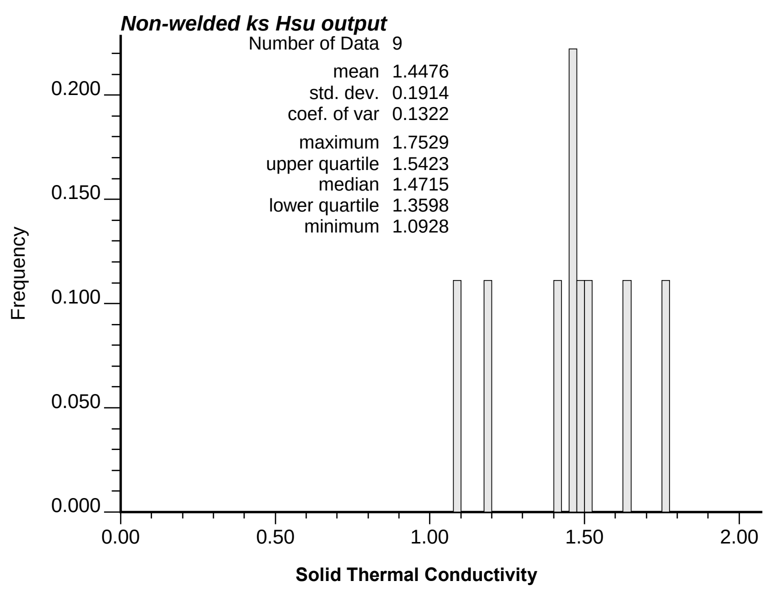
Because the mean is computed from the data rather than known from other principles, the standard deviation from HISTPLT (STN 10802-2.01-00 [DIRS 158223]) should be multiplied by sqrt(N/(N−1)). For the 0.191 standard deviation from the histogram, the standard deviation using a division by sqrt(N−1) is 0.203. By visual inspection, no standard distribution appears appropriate, so a uniform distribution is chosen. The standard deviation for a uniform distribution ranged from A to B is:

$$(B\text{-}A)/(2 \text{ sqrt } (3)) \qquad \text{(Eq. 6-7)}$$

where:

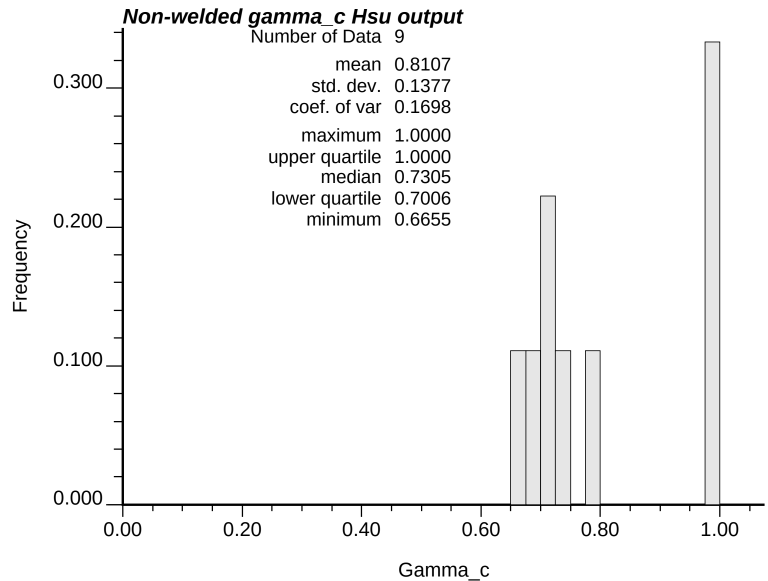
A = start value.
B = end value.
sqrt = square root operator.

The mean for a uniform distribution is (A+B)/2. Based on the known standard deviation and the mean, A and B are calculated, as shown in Table 6-12. This puts the endpoints approximately 0.352 from the mean, and results in a uniform distribution between 1.096 and 1.799. The non-welded γ_c values are shown in the histogram in Figure 6-5. By visual inspection, no standard distribution appears appropriate, so a uniform distribution is chosen, resulting in a distribution between approximately 0.621 and 1.00.



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-4. Non-welded Solid Thermal Conductivity Histogram

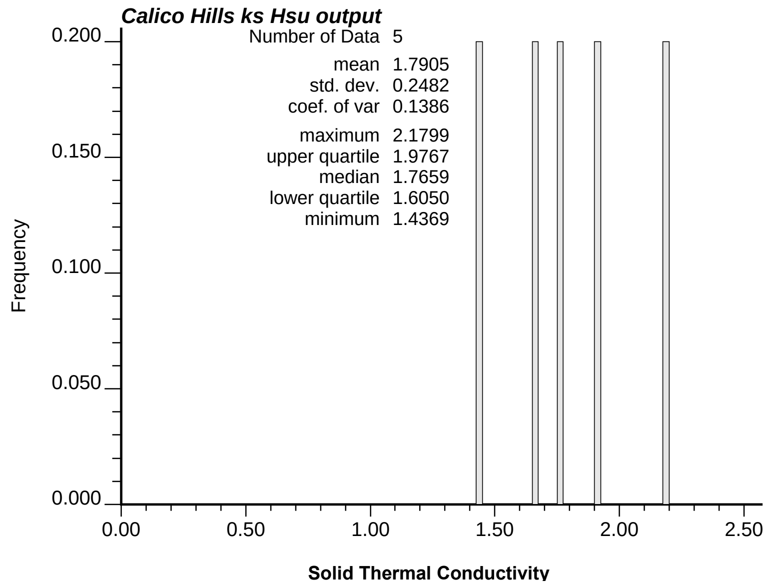


NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-5. Non-welded Gamma_c Histogram

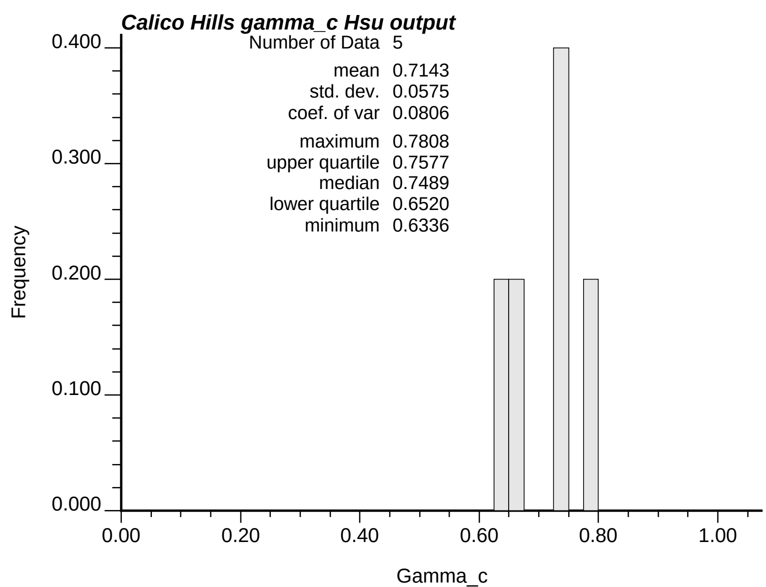
No distribution can be chosen from the vitric data because there are no data triads. A range of solid thermal conductivity for glass from the *Chemical Engineers' Handbook* (Perry and Chilton 1973 [DIRS 104946], p. 3-260), is used for the range of k_s: 0.35 to 1.26 W/m K. The distribution is assumed to be uniform. The vitric γ_c is assumed to be a constant 1.0. This is the most probable value for the welded and non-welded rock types above the Calico Hills Formation (see Section 5, Assumptions). Note that for units located away from the repository that are near saturation and are isolated from the dry out zone near the repository horizon, the predicted thermal conductivity for the saturated case based upon the Hsu model is not sensitive to the solids.

The Calico Hills k_s values are shown in the histogram in Figure 6-6. By visual inspection, no standard distribution appears appropriate, so a uniform distribution is chosen. The distribution 1.31 to 2.271 gives approximately the data mean and standard deviation. The Calico Hills γ_c values are shown in the histogram in Figure 6-7. By visual inspection, no standard distribution appears appropriate, so a uniform distribution is chosen.



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-6. Calico Hills Solid Thermal Conductivity Histogram



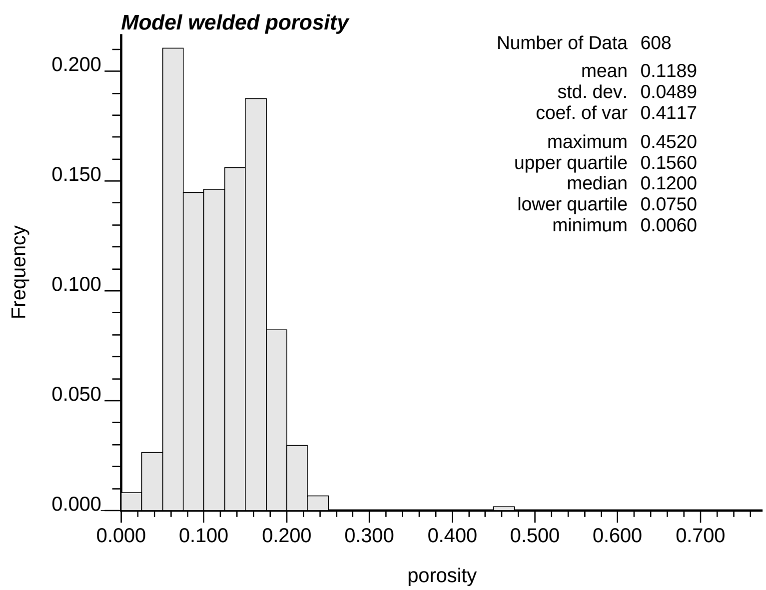
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-7. Calico Hills Gamma_c Histogram

6.5 DISTRIBUTIONS OF MATRIX POROSITY FOR WELDED, NON-WELDED, VITRIC, CALICO HILLS, PROW PASS, BULLFROG, AND TRAM TUFF UNITS

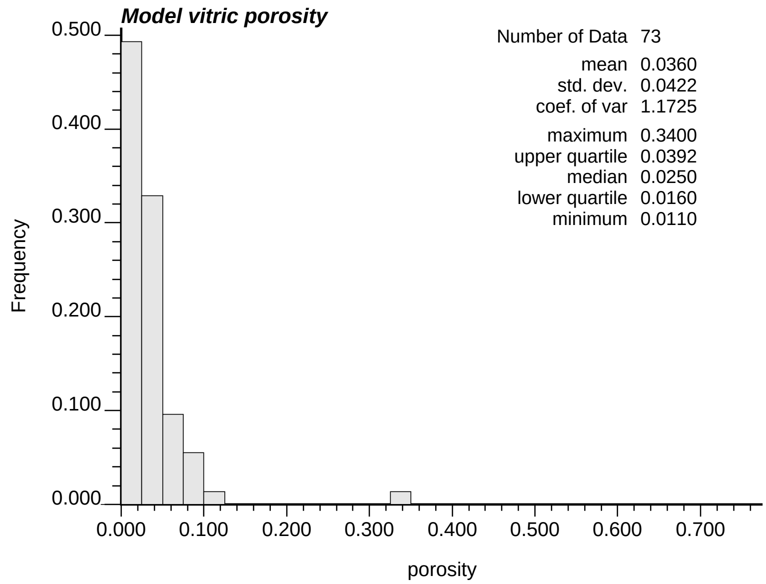
Six data tables containing qualified, verified matrix porosity data for 7 boreholes are given in Table 4-3. The wet and dry thermal conductivity values used in model building come from these boreholes, so it is appropriate to obtain ϕ_m distributions from these same boreholes. The data from these six data tables are extracted for these boreholes and put into a data file using the REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file in Appendix I; a second REFORMAT run separates the data into nine files using the REFORMAT input control file in Appendix J of this report.

The porosity data file yields 608 welded values, 73 vitric values, 351 non-welded values, 258 Calico Hills values, 421 Prow Pass non-welded values, 55 Prow Pass welded values, 54 Bullfrog non-welded values, 87 Bullfrog welded values, and 26 Tram Tuff non-welded values. Histograms of the data are shown in Figure 6-8 to Figure 6-16. No histogram is provided for the Tram Tuff welded layer because no porosity data are available. As described in Section 6.6, the Prow Pass welded layer was selected as a surrogate for the Tram Tuff welded layer.



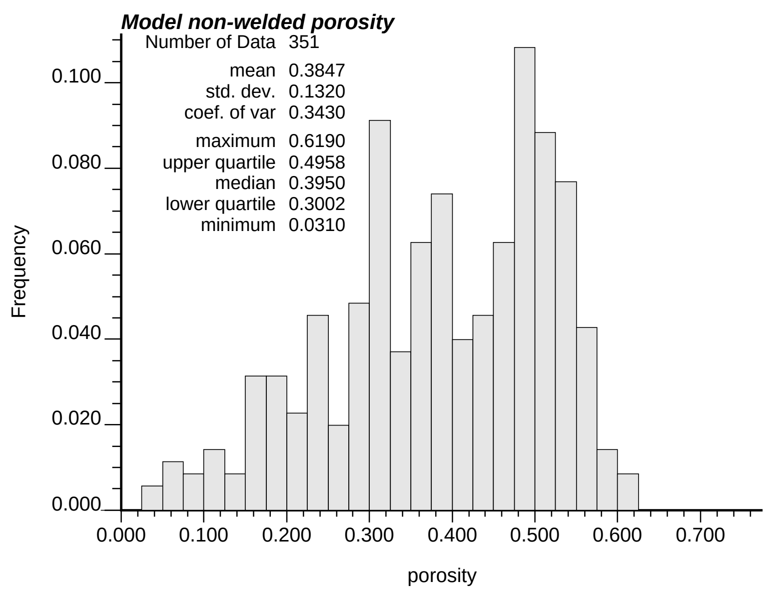
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-8. Model Welded Matrix Porosity



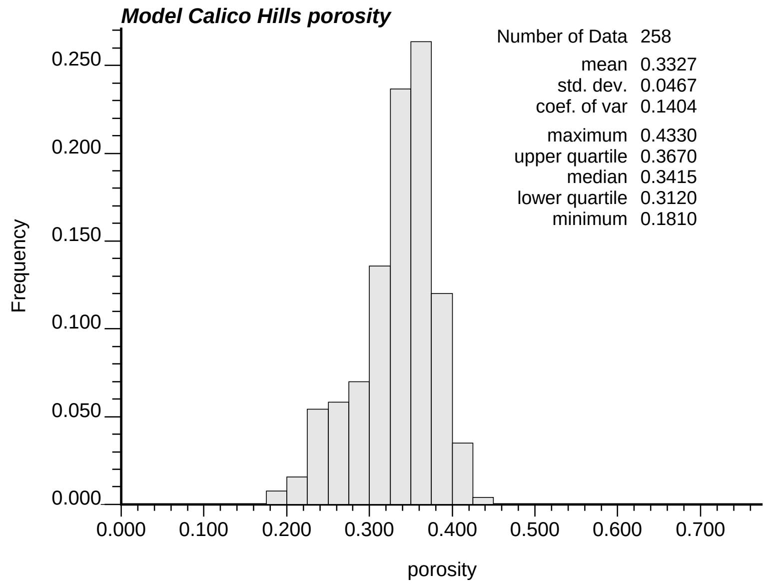
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-9. Model Vitric Matrix Porosity



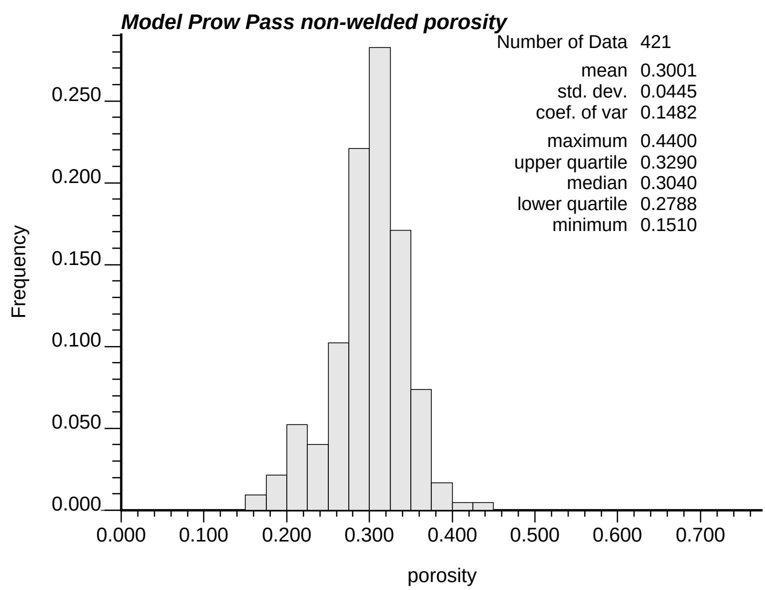
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-10. Model Non-welded Matrix Porosity



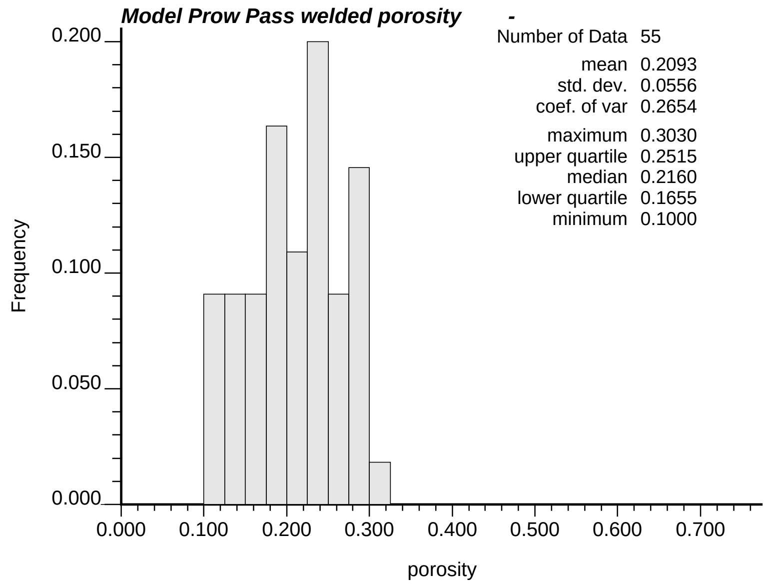
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-11. Model Calico Hills Matrix Porosity



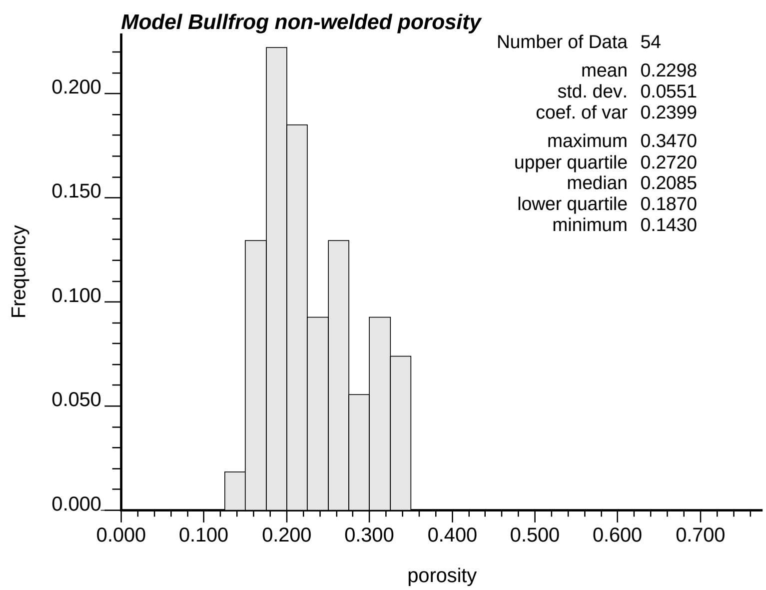
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-12. Model Prow Pass Non-welded Matrix Porosity



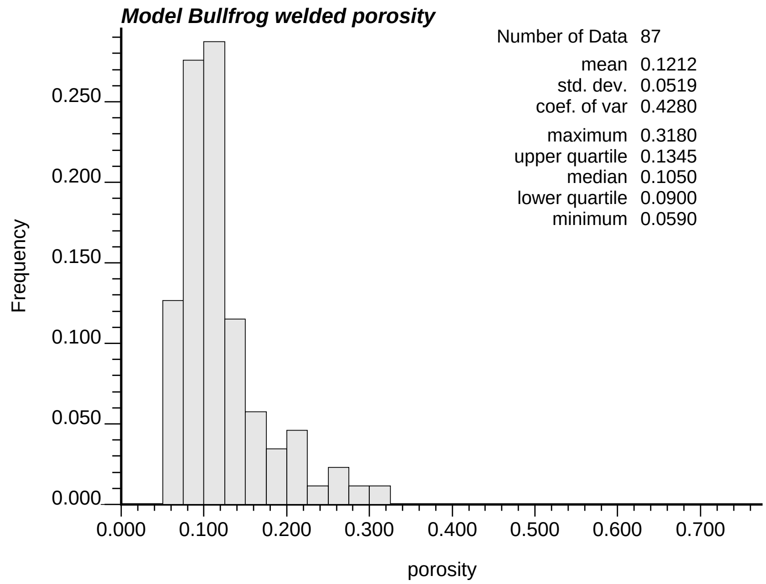
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-13. Model Prow Pass Welded Matrix Porosity



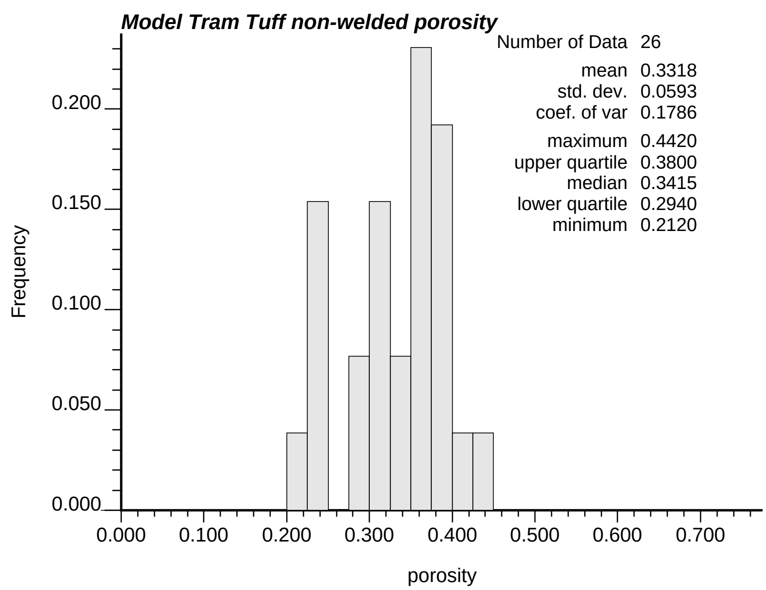
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-14. Model Bullfrog Non-welded Matrix Porosity



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-15. Model Bullfrog Welded Matrix Porosity



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 6-16. Model Tram Tuff Non-welded Matrix Porosity

6.6 DISTRIBUTIONS OF MATRIX POROSITY, GAMMA_C, AND SOLID THERMAL CONDUCTIVITY USED BY GENHSUMODELDATA

There are no k_d, k_w, ϕ_m data triads for the Prow Pass, Bullfrog, and Tram Tuff units. These units consist of welded and non-welded layers. There are, however, at least 26 values of ϕ_m for each of these layers, with the exception of the Tram Tuff non-welded layer. These data come from DTN GS000508312231.006 [DIRS 153237] data table s00415_001, DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)), DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003), DTN SNL02030193001.002 ([DIRS 120575] data tables s98484_001 and s98484_005), and DTN SNL02030193001.022 ([DIRS 109613] data table s99111_001). The thermal conductivity model for these layers is built from the inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) γ_c and k_s distributions for the welded and non-welded units above the Calico Hills Formation and the ϕ_m distributions for the Prow Pass, Bullfrog, and Tram Tuff units. Because there are no ϕ_m data for the welded Tram Tuff layer (Table U-1, GFM Unit Trammd), the results for the Prow Pass welded layer (Prowmd) (Figure 6-13) are used for Trammd because of the proximity of the layers and the similarity between the non-welded ϕ_m distributions for Prow Pass (Figure 6-12) and Tram Tuff (Figure 6-16).

With probability distributions of γ_c, k_s, and ϕ_m available for a geologic layer, GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) can be used to generate values for the wet and dry matrix thermal conductivities. The distributions for γ_c, k_s, and ϕ_m are shown in Table 6-12. Cells containing dashes (—) in Table 6-12 indicate that the data are not needed in the description of the distribution.

The qualified program GENHSUMODELDATA (STN: 10905-1.0-00 [DIRS 162671]) generates 15,625 values for wet and dry thermal conductivity using 25 values from each of the γ_c, k_s, and ϕ_m distributions. The 25 values are evenly spaced from 0.02 to 0.98 on the cumulative probability distributions. The means and standard deviations of the matrix porosity and the wet and dry thermal conductivities are presented as the thermal conductivity model output data for each geologic layer. Because the model means come from distributions, it is possible that using the mean values of ϕ_m, γ_c, and k_s as input to the Hsu model may not produce the model means. The three mean values of ϕ_m, γ_c, and k_s are connected by the Hsu model.

Dry bulk density data from boreholes USW SD-7, USW SD-9, USW SD-12, UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, and USW NRG-7 were separated into welded, non-welded, vitric, Calico Hills, Prow Pass non-welded, Prow Pass welded, Bullfrog non-welded, Bullfrog welded, Tram Tuff welded, and Tram Tuff non-welded layers. The means and standard deviations of these data were computed. The results are shown in Table 6-13 along with the matrix porosity data and the wet and dry thermal conductivity results from the program GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]).

Table 6-12. Distributions Used by Program GENHSUMODELDATA

Layer Type	Parameter	Distribution	Start	End	Mean	Standard Deviation	Growth Rate
welded	ϕ_m	normal	—	—	0.119	0.049	—
welded	k_s (W/m K)	normal	—	—	2.113	0.227	—
welded	γ_c	exponential	0.	1.	0.905	0.092	10.479
vitric	ϕ_m	exponential	0.	1	0.036	0.043	−27.778
vitric	k_s (W/m K)	uniform	0.35	1.26	0.805	0.263	—
vitric	γ_c	constant	1.	1.	1.	—	—
non-welded	ϕ_m	normal	—	—	0.385	0.132	—
non-welded	k_s (W/m K)	uniform	1.096	1.799	1.448	0.203	—
non-welded	γ_c	uniform	0.621	1.	0.811	0.146	—
Calico Hills	ϕ_m	normal	—	—	0.333	0.047	—
Calico Hills	k_s (W/m K)	uniform	1.31	2.271	1.791	0.278	—
Calico Hills	γ_c	uniform	0.603	0.826	0.714	0.064	—
Prow Pass non-welded	ϕ_m	normal	—	—	0.300	0.045	—
Prow Pass non-welded	k_s (W/m K)	uniform	1.096	1.799	1.448	0.203	—
Prow Pass non-welded	γ_c	uniform	0.621	1.	0.811	0.146	—
Prow Pass welded	ϕ_m	normal	—	—	0.209	0.056	—
Prow Pass welded	k_s (W/m K)	normal	—	—	2.113	0.227	—
Prow Pass welded	γ_c	exponential	0.	1.	0.905	0.092	10.479
Bullfrog non-welded	ϕ_m	normal	—	—	0.230	0.056	—
Bullfrog Non-welded	k_s (W/m K)	uniform	1.096	1.799	1.448	0.203	
Bullfrog Non-welded	γ_c	uniform	0.621	1.	0.811	0.146	—
Bullfrog Welded	ϕ_m	normal	—	—	0.121	0.052	—
Bullfrog Welded	k_s (W/m K)	normal	—	—	2.113	0.227	—
Bullfrog Welded	γ_c	exponential	0.	1.	0.905	0.092	10.479
Tram Tuff Non-welded	ϕ_m	normal	—	—	0.332	0.061	—
Tram Tuff Non-welded	k_s (W/m K)	uniform	1.096	1.799	1.448	0.203	—
Tram Tuff Non-welded	γ_c	uniform	0.621	1.	0.811	0.146	—

Table 6-12. Distributions Used by Program GENHSUMODELDATA (Continued)

LayerType	Parameter	Distribution	Start	End	Mean	Standard Deviation	Growth Rate
Tram Tuff Welded	ϕ_m	normal	—	—	0.209	0.056	—
Tram Tuff Welded	k_s (W/m K)	normal	—	—	2.113	0.227	—
Tram Tuff Welded	γ_c	exponential	0.	1.	0.905	0.092	10.479

NOTES: This table was assembled manually from visual inspection and output from Figure 6-2 to Figure 6-16 generated by HISTPLT (STN: 10802-2.01-00 [DIRS 158223]).

The standard deviation for a uniform distribution ranged from A to B is:

(B−A)/(2 sqrt (3))

where:

A = start value; B = end value; sqrt = square root operator.

The mean for a uniform distribution is (A+B)/2.

A and B are based on the known standard deviation and the mean. The standard deviation in the table is obtained using a division by sqrt(N−1).

The input data are from:

DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN GS000508312231.006 ([DIRS 153237] data table s00415_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file DATAQ.zip)),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002),
DTN SNL01A05059301.007 ([DIRS 108980] data table s98424_003),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL02030193001.002 ([DIRS 120575] data tables s98484_001 and s98484_005), and
Perry and Chilton (1973 [DIRS 104946], Table 3-320).

Cells containing dashes (—) indicate that the data are not needed in the description of the distribution.

Table 6-13. Thermal Conductivity Model Results

Geologic Framework Model Unit [a]	Thermal Conductivity					Matrix Porosity			Dry Bulk Density (kg/m^3)			Layer Character-ization
		Dry Matrix Thermal Conductivity (W/m K)		Wet Matrix Thermal Conductivity (W/m K)								
	# points	mean	std dev	mean	std dev	# points	mean	std dev	# points	mean	std dev	
Crystal-Rich Tiva/Post-Tiva	17	1.30E0	2.31E−1	1.81E0	1.95E−1	608	1.19E−1	4.89E−2	1323	2.19E3	1.77E2	welded
Tpcp	17	1.30E0	2.31E−1	1.81E0	1.95E−1	608	1.19E−1	4.89E−2	1323	2.19E3	1.77E2	welded
TpcLD	17	1.30E0	2.31E−1	1.81E0	1.95E−1	608	1.19E−1	4.89E−2	1323	2.19E3	1.77E2	welded
Tpcpv3	2	6.88E−1	2.29E−1	7.96E−1	2.51E−1	73	3.60E−2	4.25E−2	118	2.31E3	8.86E1	vitric
Tpcpv2	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tpcpv1	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tpbt4	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Yucca	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tpbt3_dc	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Pah	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tpbt2	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tptrv3	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tptrv2	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tptrv1	2	6.88E−1	2.29E−1	7.96E−1	2.51E−1	73	3.60E−2	4.25E−2	118	2.31E3	8.86E1	vitric
Tptrn	17	1.30E0	2.31E−1	1.81E0	1.95E−1	608	1.19E−1	4.89E−2	1323	2.19E3	1.77E2	welded
Tptrl	17	1.30E0	2.31E−1	1.81E0	1.95E−1	608	1.19E−1	4.89E−2	1323	2.19E3	1.77E2	welded
Tptf	17	1.30E0	2.31E−1	1.81E0	1.95E−1	608	1.19E−1	4.89E−2	1323	2.19E3	1.77E2	welded
Tptpv3	2	6.88E−1	2.29E−1	7.96E−1	2.51E−1	73	3.60E−2	4.25E−2	118	2.31E3	8.86E1	vitric
Tptpv2	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tptpv1	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Tpbt1	9	4.90E−1	1.58E−1	1.06E0	1.46E−1	351	3.85E−1	1.32E−1	594	1.46E3	3.37E2	non-welded
Calico	5	5.95E−1	1.12E−1	1.26E0	1.41E−1	258	3.33E−1	4.68E−2	611	1.67E3	1.57E2	calico

Table 6-13. Thermal Conductivity Model Results (Continued)

Geologic Framework Model Unit [a]	Thermal Conductivity					Matrix Porosity			Dry Bulk Density (kg/m^3)			Layer Character-ization
		Dry Matrix Thermal Conductivity (W/m K)		Wet Matrix Thermal Conductivity (W/m K)								
	# points	mean	std dev	mean	std dev	# points	mean	std dev	# points	mean	std dev	
Calicobt	5	5.95E−1	1.12E−1	1.26E0	1.41E−1	258	3.33E−1	4.68E−2	611	1.67E3	1.57E2	calico
Prowuv	9	5.69E−1	1.04E−1	1.13E0	1.17E−1	421	3.00E−1	4.46E−2	508	1.79E3	1.17E2	non-welded
Prowuc	9	5.69E−1	1.04E−1	1.13E0	1.17E−1	421	3.00E−1	4.46E−2	508	1.79E3	1.17E2	non-welded
Prowmd	17	1.06E0	1.83E−1	1.63E0	1.68E−1	55	2.09E−1	5.61E−2	81	2.07E3	1.39E2	welded
Prowlc	9	5.69E−1	1.04E−1	1.13E0	1.17E−1	421	3.00E−1	4.46E−2	508	1.79E3	1.17E2	non-welded
Prowlv	9	5.69E−1	1.04E−1	1.13E0	1.17E−1	421	3.00E−1	4.46E−2	508	1.79E3	1.17E2	non-welded
Prowbt	9	5.69E−1	1.04E−1	1.13E0	1.17E−1	421	3.00E−1	4.46E−2	508	1.79E3	1.17E2	non-welded
Bullfroguv	9	6.58E−1	1.30E−1	1.19E0	1.38E−1	54	2.30E−1	5.56E−2	68	1.88E3	1.67E2	non-welded
Bullfroguc	9	6.58E−1	1.30E−1	1.19E0	1.38E−1	54	2.30E−1	5.56E−2	68	1.88E3	1.67E2	non-welded
Bullfrogmd	17	1.30E0	2.39E−1	1.81E0	1.98E−1	87	1.21E−1	5.22E−2	92	2.26E3	1.38E2	welded
Bullfroglc	9	6.58E−1	1.30E−1	1.19E0	1.38E−1	54	2.30E−1	5.56E−2	68	1.88E3	1.67E2	non-welded
Bullfroglv	9	6.58E−1	1.30E−1	1.19E0	1.38E−1	54	2.30E−1	5.56E−2	68	1.88E3	1.67E2	non-welded
Bullfrogbt	9	6.58E−1	1.30E−1	1.19E0	1.38E−1	54	2.30E−1	5.56E−2	68	1.88E3	1.67E2	non-welded
Tramuv	9	5.35E−1	1.06E−1	1.10E0	1.16E−1	26	3.32E−1	6.05E−2	37	1.76E3	1.95E2	non-welded
Tramuc	9	5.35E−1	1.06E−1	1.10E0	1.16E−1	26	3.32E−1	6.05E−2	37	1.76E3	1.95E2	non-welded
Trammd	17	1.06E0	1.83E−1	1.63E0	1.68E−1	55	2.09E−1	5.61E−2	2	2.14E3	7.78E1	welded
Tramlc	9	5.35E−1	1.06E−1	1.10E0	1.16E−1	26	3.32E−1	6.05E−2	37	1.76E3	1.95E2	non-welded
Tramlv	9	5.35E−1	1.06E−1	1.10E0	1.16E−1	26	3.32E−1	6.05E−2	37	1.76E3	1.95E2	non-welded
Trambt	9	5.35E−1	1.06E−1	1.10E0	1.16E−1	26	3.32E−1	6.05E−2	37	1.76E3	1.95E2	non-welded

Table 6-13. Thermal Conductivity Model Results (Continued)

Sources:
DTN MO0004QGFMPICK.000 ([DIRS 152554] data table s00214_001),
DTN GS000508312231.006 ([DIRS 153237] data table s00415_001),
DTN MO0109HYMXPROP.001 ([DIRS 155989] data table s01144_001 (file *DATAQ.zip*)),
DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001),
DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002),
DTN SNL01A05059301.007 ([DIRS 108980] data tables s98424_001 and s98424_003),
DTN SNF40060298001.001 ([DIRS 107372] data table s98430_001),
DTN SNL02030193001.002 ([DIRS 120575] data tables s98484_001, s98484_002, s98484_004, and s98484_005),
DTN GS000408312231.004 ([DIRS 149582] data table s00276_001),
DTN GS950308312231.002 ([DIRS 108990] data table s96015_001),
DTN GS950408312231.004 ([DIRS 108986] data table s96021_001),
DTN GS940508312231.006 ([DIRS 107149] data table s96024_003),
DTN GS930108312231.006 ([DIRS 108997] data tables s96025_001 and s96025_002),
DTN GS920508312231.012 ([DIRS 109001] data tables s96026_001,
DTN GS940408312231.004 ([DIRS 109000] data table s96027_001),
DTN GS951108312231.009 ([DIRS 108984] data table s96037_001),
DTN GS951108312231.010 ([DIRS 108983] data table s96046_001),
DTN GS951108312231.011 ([DIRS 108992] data table s96049_001),
DTN GS960808312231.004 ([DIRS 108985] data table s97058_001),
DTN GS920408312314.011 ([DIRS 129660] data table s97135_002),
DTN GS930408312132.007 ([DIRS 129625] data table s97276_001),
DTN GS980708312242.010 ([DIRS 106752] data table s98248_004),
DTN GS980808312242.014 ([DIRS 106748] data table s98285_001),
DTN SNL02030193001.004 ([DIRS 108415] data tables s98485_001 and s98485_003),
DTN SNL02030193001.008 ([DIRS 120597] data table s98486_001),
DTN SNL02030193001.003 ([DIRS 120578] data tables s99100_001 and s99100_004),
DTN SNL02030193001.006 ([DIRS 120579] data table s99101_001 and s99101_004),
DTN SNL02030193001.013 ([DIRS 120614] data table s99104_001 and S99104_004) [b],
DTN SNL02030193001.005 ([DIRS 122545] data table s99105_001 and S99105_004) [c],
DTN SNL02030193001.007 ([DIRS 120582] data table s99106_001),
DTN SNL02030193001.014 ([DIRS 109609] data tables s99107_001 and s99107_004),
DTN SNL02030193001.015 ([DIRS 120617] data table s99108_001),
DTN SNL02030193001.009 ([DIRS 109614] data table s99109_001 and s99109_002) [d],
DTN SNL02030193001.012 ([DIRS 108416] data table s99110_001),
DTN SNL02030193001.022 ([DIRS 109613] data tables s99111_001 and s99111_002),
DTN SNL02030193001.016 ([DIRS 120619] data table s99112_001),
DTN SNL02030193001.017 ([DIRS 109610] data table s99113_001),
DTN SNL02030193001.018 ([DIRS 109611] data table s99114_001),
DTN SNL02030193001.019 ([DIRS 108431] data tables s99115_001 and s99115_002),
DTN SNL02030193001.020 ([DIRS 108432] data tables s99116_001 and s99116_004),
DTN SNL02030193001.021 ([DIRS 108433] data table s99117_001), and
DTN SNL01A05059301.002 ([DIRS 150042] data table s99435_001).

NOTE: This table is included in output DTN SN0303T0503102.008 (file: *TC_CD\Outputs\Genhsumodeldata\finalstats*).

[a] Model Unit corresponds to the Geologic Framework Model Unit listed in Table U-1.
[b] Data table S99104_004 was excluded because the data are for an alluvium layer not considered in this report.
[c] Data table S99105_004 was excluded because the lithostratigraphy correlation data (DTN MO0004QGFMPICK.000 [DIRS 152554]) are not available for UE-25 NRG #3.
[d] Data table S99109_001 was excluded because the data are for the repository layers not considered in this report.

Table 6-13 represents the numerical output for the thermal conductivity model and is available with some additional notes as Product Output DTN SN0303T0503102.008. The measurement uncertainties described in Section 6.2 are all small compared to the 95 percentile ranges (two or more standard deviations, depending on the number of measurements) of the model results in Table 6-13. The standard-deviation range for Tram Tuff non-welded wet thermal conductivity is approximately 11 percent of the mean, or 0.116. This is the smallest uncertainty for any thermal conductivity model value. The 5-percent measurement uncertainty, taken to have 95-percent confidence, is 2.5 percent of the mean, or an absolute value of 0.028. The combined standard deviation is found by taking the square root of the sum of the variances, giving 0.119. The thermal conductivity measurement uncertainty causes a negligible change in the standard deviation and, therefore, can be ignored.

The porosity measurement uncertainty is approximately 5 percent (absolute) for porosities less than 0.11. Only the vitric porosity falls in this range. The standard deviation of the vitric mean porosity is 0.0425. The 5-percent absolute measurement uncertainty corresponds to a 0.025 standard deviation. The combined standard deviation is 0.0493 (from $\mathrm{sqrt}(0.0425^2+0.025^2)$), which is close enough to the numerical standard deviation to ignore the measurement uncertainty. For porosities greater than 0.11, the measurement uncertainty is approximately 9 percent of the measured value. The smallest standard deviation is 0.0446 for Prow Pass non-welded. The measurement standard deviation would be approximately 0.0135 (absolute), which is negligible compared to the standard deviation.

6.7 DRY BULK DENSITY ANALYSIS

The program REFORMAT (STN 10907-2.0-00 [DIRS 162673]) uses the control input file in Appendix K to convert the 48 dry bulk density data tables into one table of 5,030 values with lithostratigraphy appended. In tables that included both 105°C oven and relative humidity oven measurements, the relative humidity measurements were used. The control input file in Appendix L enables REFORMAT (STN 10907-2.0-00 [DIRS 162673]) to rewrite the data into tables for welded, non-welded, vitric, Calico Hills, Prow Pass non-welded, Prow Pass welded, Bullfrog non-welded, Bullfrog welded, Tram Tuff non-welded, and Tram Tuff welded units. This analysis includes all available qualified, verified dry bulk density data available as of February 13, 2003.

Mean and standard deviations for the 10 categories are obtained from the program HISTPLT (STN 10802-2.01-00 [DIRS 158223]). The results are converted from centimeter-gram-second units to the International System of Units and the standard deviations are converted to sample-mean standard deviations. The results are shown in Table 6-13. The Tram Tuff welded value is based on two measurements and should be considered less reliable than the other values. The remaining units consist of from 37 to 1,323 values. The dry bulk density data are averaged from available data, and are not a model; therefore, it does not require a separate validation.

The standard deviations for dry bulk density (Table 6-13) range from 4 to 23 percent of the means. Because the measurement uncertainty (Section 6.2) is approximately 0.4 percent, the measurement uncertainty is negligible in comparison, and can be ignored.

6.8 IMPACT OF THE CHOICE OF DISTRIBUTION TYPE ON THERMAL CONDUCTIVITY VALUES

GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) computes 15,625 values of wet and dry thermal conductivity from 25 values from the matrix porosity (ϕ_m) distribution, 25 values from the solid thermal conductivity (k_s) distribution, and 25 values from the distribution of the geometric parameter (γ_c). The averages of the 15,625 wet and dry thermal conductivity values are the value used as the model output. The porosity distributions (Figure 6-8 to Figure 6-16) are based on 26 to 603 data points, and the choice of distribution is much less subject to interpretation than the choice of the non-welded k_s (Figure 6-4), non-welded γ_c (Figure 6-5), and Calico Hills γ_c (Figure 6-7) distributions. The uniform, exponential, and normal distributions used by GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) are each built from the mean and standard deviation of the experimental data, so each distribution type will generate 25 values with the same range and mean, but the spacing of the values will differ somewhat. The 25 data points on each of the porosity and γ_c distributions remain unchanged. For this reason it is reasonable that the averages of the 15,625 wet and dry thermal conductivity values will not differ significantly.

Consider the non-welded solid thermal conductivity distribution from Figure 6-4. A uniform distribution was used to approximate the distribution, and GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) gave a dry thermal conductivity mean of 0.4902 with a standard deviation of 0.1578 and a wet thermal conductivity mean of 1.0587 with a standard deviation of 0.1459. If a normal distribution is used for k_s, GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) gives a dry thermal conductivity mean of 0.4902 with a standard deviation of 0.1572 and a wet thermal conductivity mean of 1.0588 with a standard deviation of 0.1445. The changes in the means, 0 and 0.0001, are negligible. The changes in the standard deviations, 0.0006 and 0.0014, are less than 1 percent relative error, and also are negligible.

Now consider the non-welded γ_c distribution from Figure 6-5. If normal distributions are used instead of uniform distributions for both k_s and γ_c, GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) gives a dry thermal conductivity mean of 0.4837 with a standard deviation of 0.1597 and a wet thermal conductivity mean of 1.0587 with a standard deviation of 0.1445. The changes in the means, 0.0065 and 0.0, and the changes in the standard deviations, 0.0019 and 0.0014, are all less than 1.5-percent relative error, and are therefore negligible.

7. VALIDATION

7.1 CONFIDENCE BUILDING DURING MODEL DEVELOPMENT TO ESTABLISH SCIENTIFIC BASIS AND ACCURACY FOR INTENDED USE

Section 2.2.2.2 of TWP-MGR-PA-000019 REV 00 ICN 1 (BSC 2004 [DIRS 171708]) identifies this *Thermal Conductivity of Non-Repository Lithostratigraphic Layers* report as requiring Level I model validation per AP-2.27Q. AP-2.27Q specifies the following steps for *Confidence Building During Model Development*:

> The development of the model should be documented in accordance with the requirements of Section 5.3.2(b) of AP-SIII.10Q.

The development of the *Thermal Conductivity of Non-Repository Lithostratigraphic Layers* report has been conducted in accordance with these criteria, as follows:

1. *Selection of input parameters and/or input data, and a discussion of how the selection process builds confidence in the model [AP-SIII.10Q, 5.3.2(b) (1) and AP-2.27Q, Attachment 3, Level I (a)].*

The inputs to the model are obtained from controlled sources as described in Section 4. Qualified matrix porosity and thermal conductivity data that were previously verified are used to generate the Hsu model for thermal conductivity for the nonrepository layers of the Yucca Mountain site. The SEP parameters “porosity” and “thermal conductivity” were searched for all qualified data tables that have been verified. SEP tables containing data exclusively for the repository layers or for materials other than geologic layers (e.g., titanium or grout) are not considered because the scope of the model is limited to nonrepository geologic layers of Yucca Mountain. Only data tables that included lithostratigraphy and depth, and either borehole ID or sample ID (because one of these items is necessary to determine the lithostratigraphic layer), were retained for consideration. Porosity data other than matrix porosity data were excluded from consideration because the Hsu model requires matrix porosity and wet and dry thermal conductivity as inputs. Matrix porosity data are obtained from laboratory core measurements. Data sources are described in greater detail in Section 4 tables. The selection of site-specific data provides additional confidence that the thermal conductivity model provides results that are appropriate for the intended use. Therefore, this criterion is considered to be met.

2. *Description of calibration activities, and/or initial boundary condition runs, and/or run convergences, simulation conditions set up to span the range of intended use and avoid inconsistent outputs, and a discussion of how the activity or activities build confidence in the model. Inclusion of a discussion of impacts of any non-convergence runs [(AP-SIII.10Q, 5.3.2(b)(2) and AP-2.27Q, Attachment 3, Level I (e)].*

The Thermal Conductivity of Non-Repository Lithostratigraphic Layers is a static model, and therefore discussion of run convergences or non-convergences is not generally applicable. The use of site-specific data for inputs to the model and consistent use of the GFM stratigraphy builds confidence in the model. Discussion about initial boundary conditions and non-convergence runs is not relevant for this model report. Thus, this requirement is considered satisfied.

3. *Discussion of the impacts of uncertainties to the model results including how the model results represent the range of possible outcomes consistent with important uncertainties [(AP-SIII.10 Q, 5.3.2(b)(3) and AP-2.27Q, Attachment 3, Level 1 (d) and (f)].*

Section 6.2 and Appendix A describe the uncertainties associated with data measurement.

Section 6.4 describes distributions of gamma_c and solid thermal conductivity for welded, non-welded, vitric, and calico rock types.

Section 6.5 describes distributions of matrix porosity, for welded, non welded, vitric, Calico Hills, Prow Pass, Bullfrog, and Tram Tuff units.

Section 6.8 provides a discusion of the impacts of the choice of distribution type on model results.

Appendix S provides a detailed uncertainty analysis of the Thermal Conductivity on the Non Repository Lithostratigraphic Layers, to assess the significance of the nonrepository horizon units on the repository temperature over extended periods of time. Regression and error analyses presented in Section 7 indicate that model results represent the range of possible outcomes.

A summary discussion on uncertainties is given in Section 8.2.2 and Section 8.2.3.

4. *Formulation of defensible assumptions and simplifications [AP-2.27Q, Attachment 3, Level I (b)].*

Discussions of assumptions and simplifications are provided in Section 5 and Section 6.1.

5. *Consistency with physical principles, such as conservation of mass, energy, and momentum [AP-2.27Q, Attachment 3, Level I (c)].*

Consistency with physical principles is demonstrated by the evaluation of alternate conceptual and mathematical models, and the selection of the Hsu model described in Section 6.1. Appendix S provides additional details regarding the mathematical development.

7.2 CONFIDENCE BUILDING AFTER MODEL DEVELOPMENT TO SUPPORT THE SCIENTIFIC BASIS OF THE MODEL

The model validation involves two steps. First, it is shown that the porosity values used in the model development represent all remaining matrix porosity data (Assumption 1 in Section 5). The normalized differences in the averages are compared to the 95-percent confidence levels on the normal distribution. Note that the TWP specifies the 98-percent confidence level, which is less stringent than the 95-percent confidence level. Second, the model wet and dry thermal conductivity values are compared to the averages from all remaining qualified thermal conductivity data, in accordance with the TWP (BSC 2004 [DIRS 171708], Section 2.2.2). The normalized differences in the averages are compared to the 95- or 98-percent confidence levels on Student’s t-distribution because of the low numbers of data points.

For estimating the properties for the Prow Pass welded, Tram Tuff non-welded, and Tram Tuff welded layers, the model regression relationships based upon matrix porosity and saturation near the repository horizon can be used and is considered a valid model for these units because:

- These welded and nonwelded units are similar in geologic structure (matrix porosity) and mineralogy to the welded and nonwelded units near the repository for which data are available.
- As noted in Appendix S, these units that are remote to the repository do not provide a significant contribution to uncertainty in predicting repository driftwall temperatures on the basis of thermal properties of the rock mass.

Estimates of these values are obtained by linear regression in accordance with the TWP (BSC 2004 [DIRS 171708], Section 2.1.2) from the remaining seven layers using functions of matrix porosity and dry bulk density as variables.

The TWP (BSC 2004 [DIRS 171708], Section 2.2.2.2) classifies this report as Level I in terms of model importance and validation. The model does not provide any direct input to the total system performance assessment model.

The model development is done using most of the qualified, verified data for matrix porosity and thermal conductivity for Boreholes USW SD-7, USW SD-9, USW SD-12, UE-25 NRG #4, UE-25 NRG #5, USW NRG-6, and USW NRG-7. These inputs are identified in Table 4-3 and Table 4-4. All of the remaining qualified, verified data for matrix porosity and thermal conductivity are used for data for model validation. These inputs are identified in Table 4-6 and Table 4-7. There are approximately 150 thermal conductivity values and approximately 10,000 porosity values. If the model were built using approximately 30 measurements, or more, for each of ϕ_m, γ_c, and k_s, then the model and validation means could be compared using the normalized difference of the means $((\mu_1-\mu_2)/s)$ for a normal distribution, where s is the standard deviation. However, there are 17 or fewer measurements for model thermal conductivity in each geologic group and fewer than 30 measurements for validation of thermal conductivity in most of the geologic groups, so it is more appropriate to do a comparison of means using the Student's t-distribution. To meet the specified validation criteria, the magnitude of the normalized difference of the means must be smaller than the Student's coefficient for the 0.975 percentile point for 95 percent significance or the 0.99 percentile point for 98 percent significance at the appropriate number of degrees of freedom to assess the significance of a difference in means. When working with a combination of two distributions, the formulas are usually expressed in terms of the sum of squared deviations S^2, where the sum of squared deviations is related to the variance s^2 by $S^2 = N\, s^2$. The normalized difference of the means t is given by Bulmer (1979 [DIRS 111961], p. 151):

$$t = \frac{(\mu_1 - \mu_2)}{s_{combined}\sqrt{1/N_1 + 1/N_2}} \qquad \text{(Eq. 7-1)}$$

The combined variance comes from the sum-of-variances relation (Bulmer 1979 [DIRS 111961], p. 150):

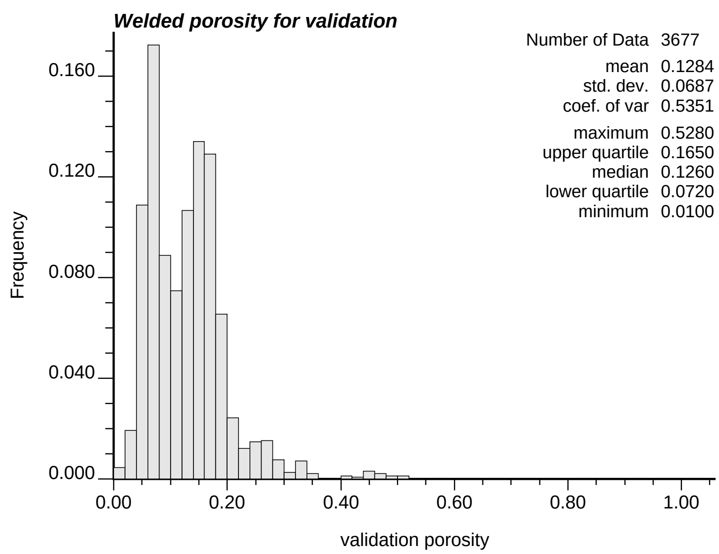
$$s^2_{combined} = \frac{(S_1^{\ 2} + S_2^{\ 2})}{(N_1 + N_2 - 2)} \qquad \text{(Eq. 7-2)}$$

where n_1 and n_2 are the counts and S_1 and S_2 are the sums of squared deviations of the model and validation data.

Model validation is accomplished by using dry bulk density data listed in Table 4-5, matrix porosity data listed in Table 4-6, and thermal conductivity data listed in Table 4-7.

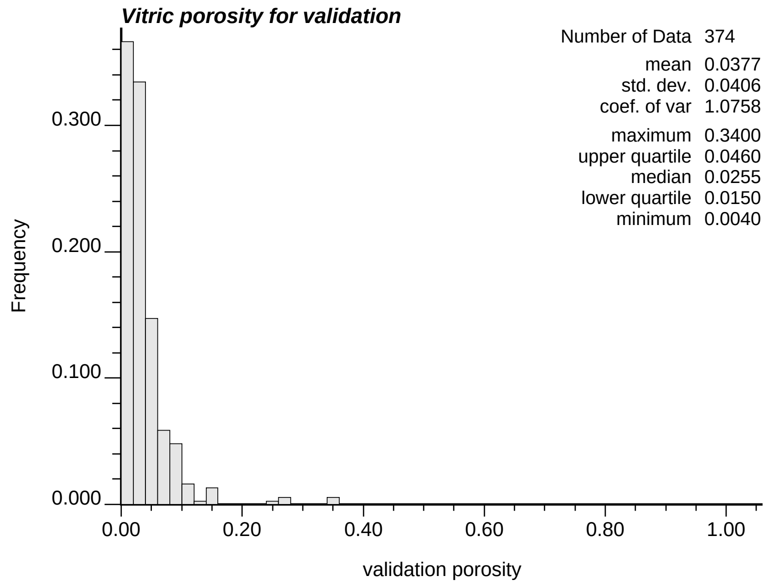
7.2.1 Porosity Validation

The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file in Appendix M of this report collects the porosity data from the 57 SEP data tables listed in Table 4-6, and puts the data into a single file. The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file in Appendix N separates the porosity data from this one file into 10 files, one for each geologic group. Figure 7-1 to Figure 7-10 show histograms of the validation porosities generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]). The numbers of points, means, and standard deviations shown in Figures 7-1 to 7-10 provide the data for the columns headed N_2, μ_2, and s_2 in Table 7-1. Because the combined number of model and validation data points is at least 57, the comparison of the means can be done using the normal distribution, where the normalized difference of the means is $(\mu_1-\mu_2)/s$. The critical normalized difference in the means is approximately 1.96 at the 95-percent confidence level. Table 7-1 shows that all the normalized differences in mean values (column t in Table 7-1) are 0.749 or smaller in magnitude, so the model and validation mean porosities are statistically equivalent; therefore, in terms of porosity, the model meets the 98-percent confidence criteria (BSC 2004 [DIRS 171708]) which is less stringent than the 95-percent interval shown above, and is validated for its intended use. Because the means are always within one combined standard deviation ($s_{combined}$) of each other, this result is not unexpected.



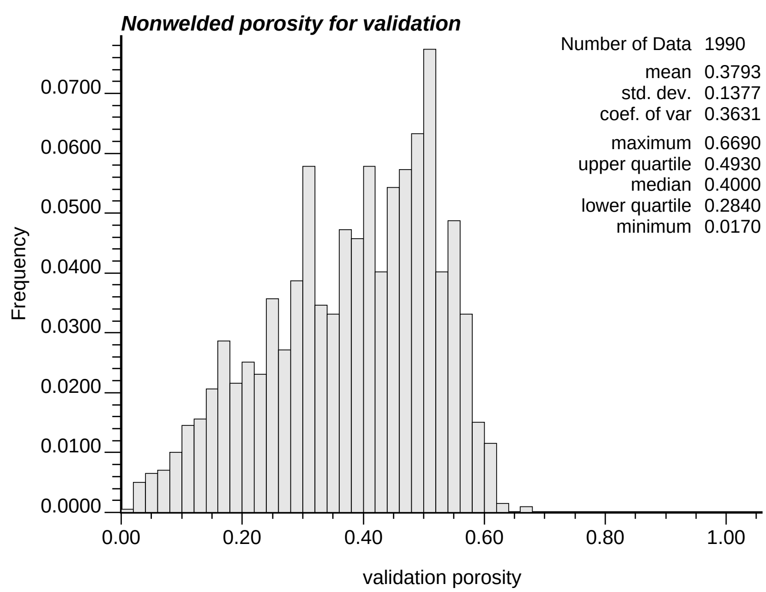
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-1. Validation Welded Matrix Porosity



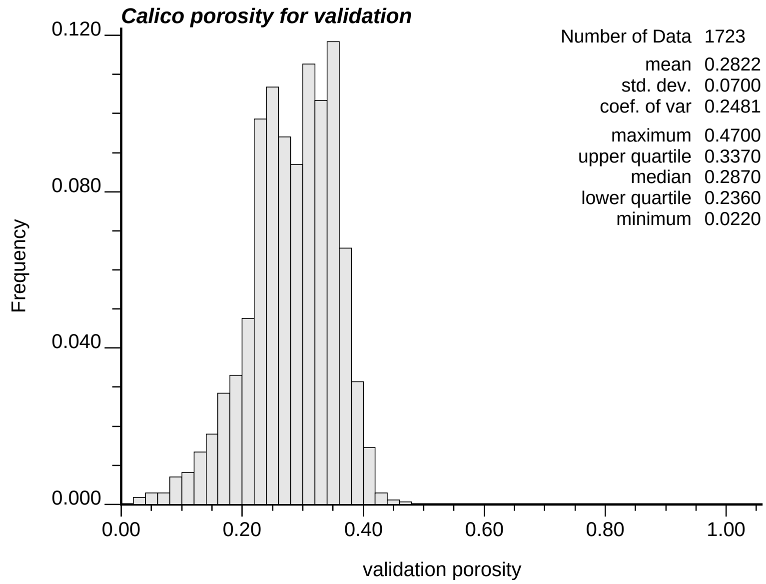
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-2. Validation Vitric Matrix Porosity



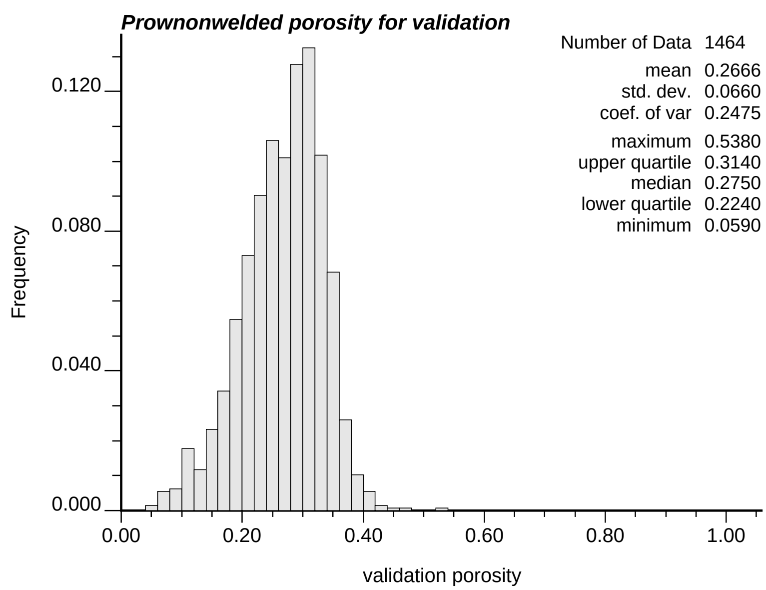
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-3. Validation Non-welded Matrix Porosity



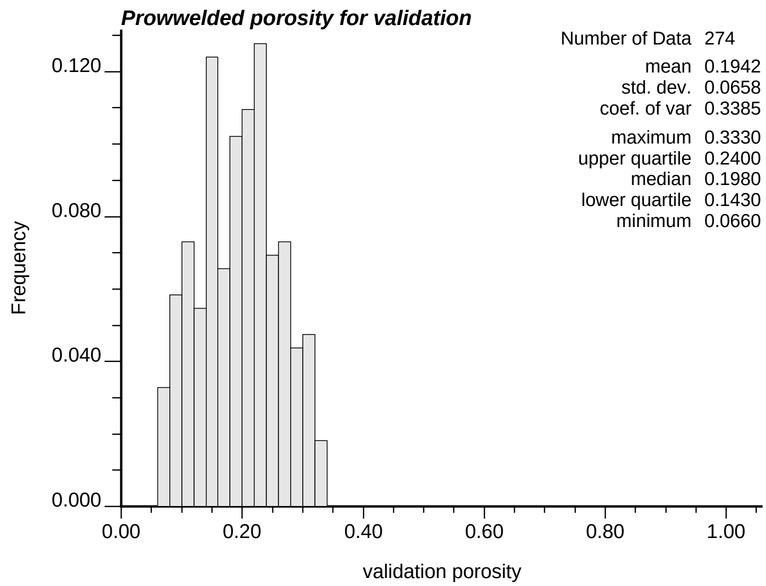
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-4. Validation Calico Hills Matrix Porosity



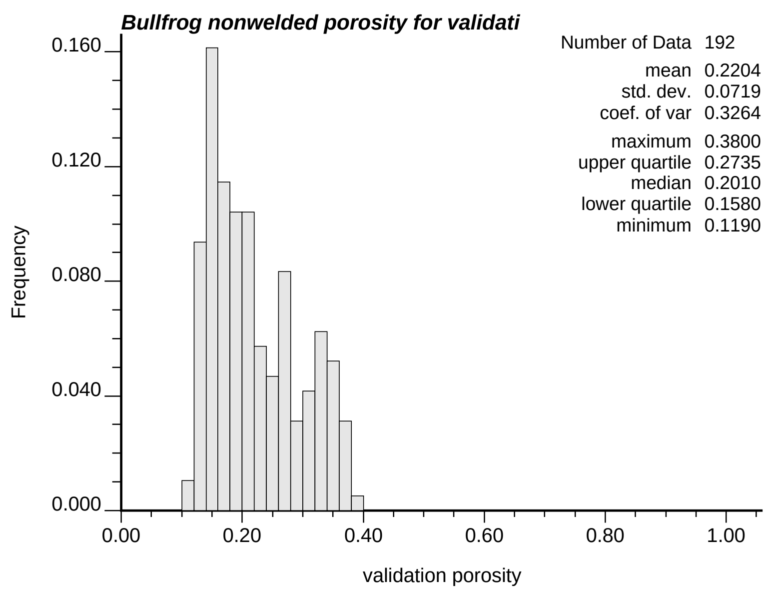
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-5. Validation Prow Pass Non-welded Matrix Porosity



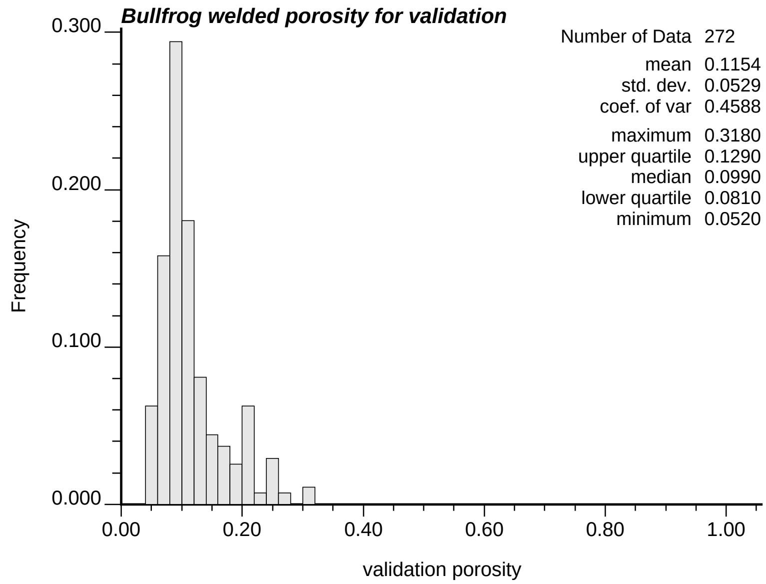
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-6. Validation Prow Pass Welded Matrix Porosity



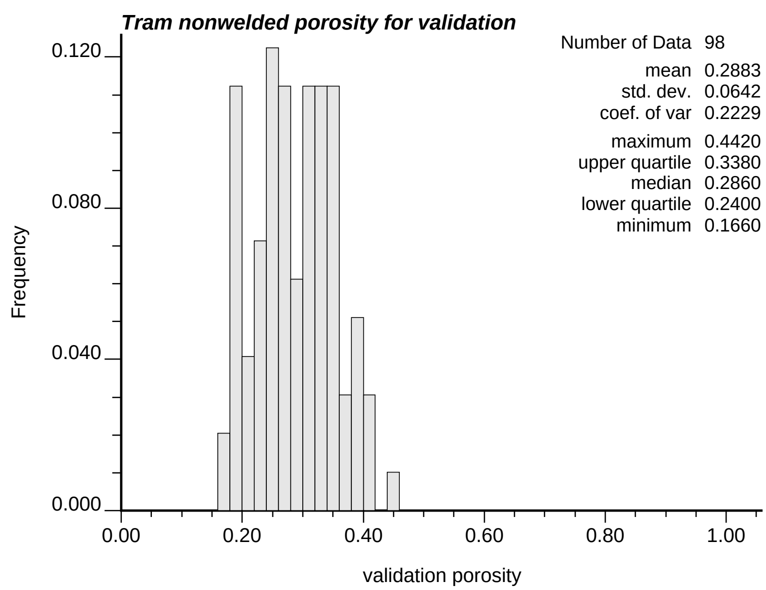
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-7. Validation Bullfrog Non-welded Matrix Porosity



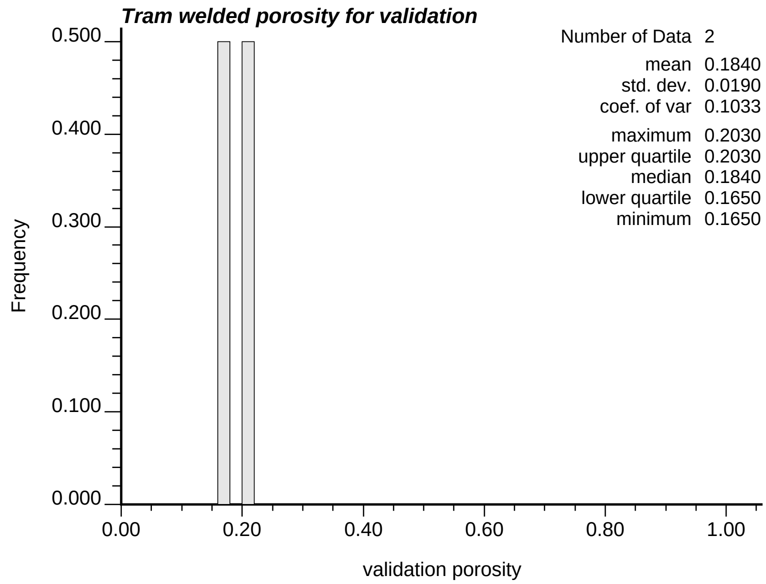
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-8. Validation Bullfrog Welded Matrix Porosity



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-9. Validation Tram Tuff Non-welded Matrix Porosity



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-10. Validation Tram Tuff Welded Matrix Porosity

Table 7-1. Validation of the Representative Borehole Assumption for Porosity

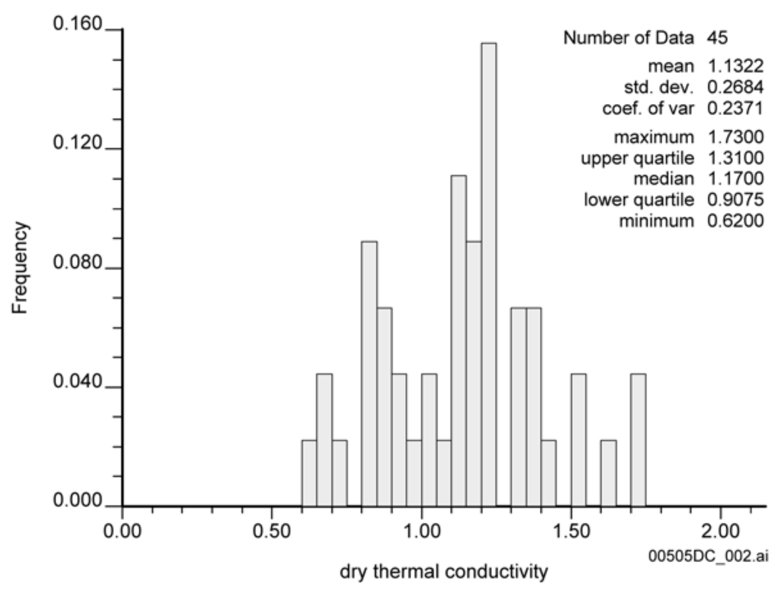
Layer	Model				Validation				$s_{combined}$	t
	N_1	μ_1	s_1	S_1	N_2	μ_2	s_2	S_2		
welded	608	0.119	0.049	1.206	3677	0.128	0.069	4.166	0.066	−0.143
vitric	73	0.036	0.042	0.361	374	0.038	0.041	0.785	0.041	−0.042
non-welded	351	0.385	0.132	2.473	1990	0.379	0.138	6.143	0.137	0.039
Calico Hills	258	0.333	0.047	0.750	1723	0.282	0.070	2.906	0.067	0.749
Prow Pass non-welded	421	0.300	0.045	0.913	1464	0.267	0.066	2.525	0.062	0.541
Prow Pass welded	55	0.209	0.056	0.412	274	0.194	0.066	1.089	0.064	0.234
Bullfrog non-welded	54	0.230	0.055	0.405	192	0.220	0.072	0.996	0.069	0.137
Bullfrog welded	87	0.121	0.052	0.484	272	0.115	0.053	0.872	0.053	0.110
Tram Tuff non-welded	26	0.332	0.059	0.302	98	0.288	0.064	0.636	0.064	0.683
Tram Tuff welded	55	0.209	0.056	0.412	2	0.184	0.019	0.027	0.056	0.454

NOTES: This table was generated by using data from Table 6-13, and Figure 7-1 to Figure 7-10. Column $s_{combined}$ and column t were generated through the use of the equation for normal distribution $t = (\mu_1 - \mu_2)/s_{combined}$ and Equation 7-2.

7.2.2 Regression Analysis of Validation Thermal Conductivity

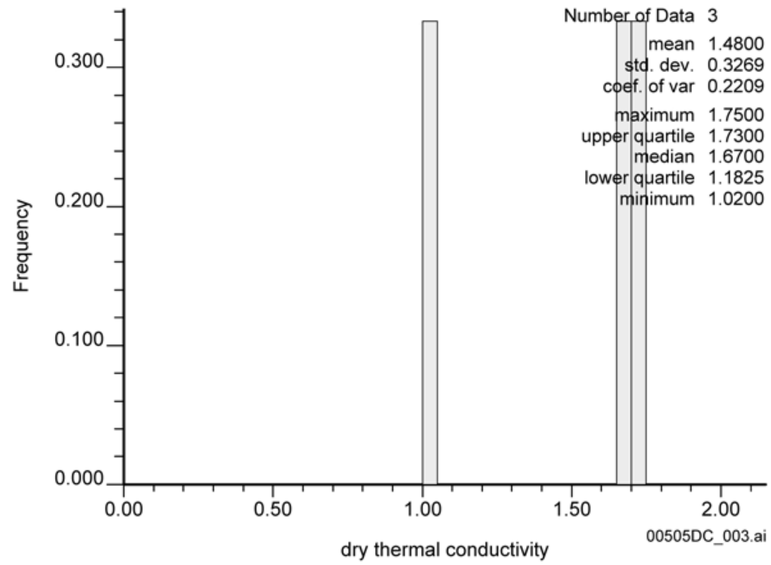
The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file in Appendix O collects the thermal conductivity data not used for model development from three SEP data tables (DTN SN0011T0571897.014 ([DIRS 154449] data table s00441_001), DTN SNL01A05059301.005 ([DIRS 109002] data table s96370_001), and DTN SNL22100196001.006 ([DIRS 158213] data table s98169_002)), and puts the data into one file. The REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input control file in Appendix P separates the thermal conductivity data from this one file into 20 files, wet and dry data for each of the ten geologic groups. Six of these files have no data in them. Figure 7-11 to Figure 7-24 show histograms of the validation dry and wet thermal conductivities generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]).

Figure 7-11 to Figure 7-24 provide means and standard deviations for wet and dry thermal conductivity for seven of the ten layers in the model. There are no model validation thermal conductivity values for the Prow Pass welded rock unit, the Tram Tuff welded rock unit, or the Tram Tuff non-welded rock unit. Because average matrix porosity values and average dry bulk density values were available for these rock units, linear regression was used to develop fits to the values for model validation dry and wet thermal conductivities as functions of these parameters. The Hsu-model equations are not useful in this analysis, because they include a geometric factor that is not available for the model validation data. The form of the regression equation was arrived at in the following manner. A relationship was found between thermal conductivity, porosity, and bulk density using a series of regression analyses.



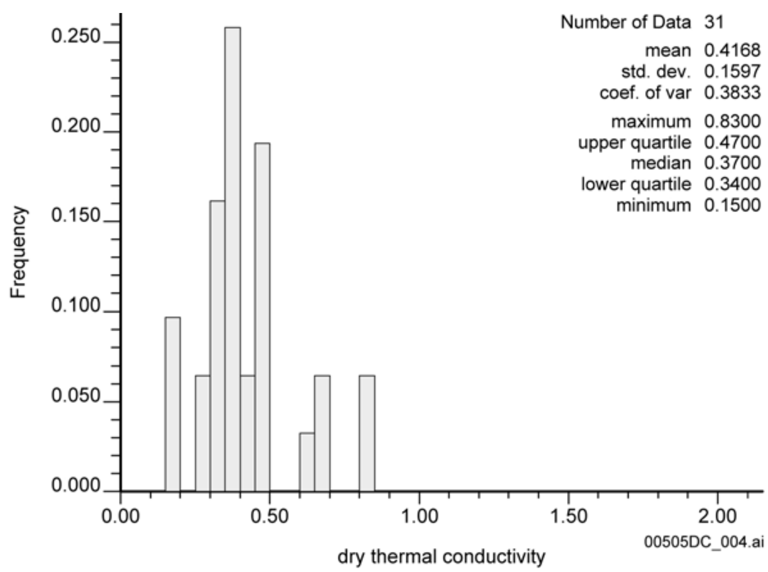
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-11. Validation Welded Dry Thermal Conductivity



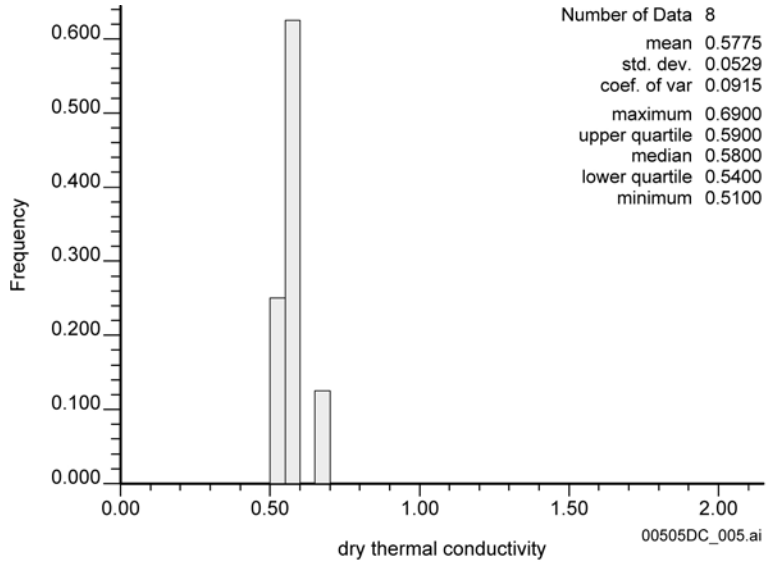
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-12. Validation Vitric Dry Thermal Conductivity



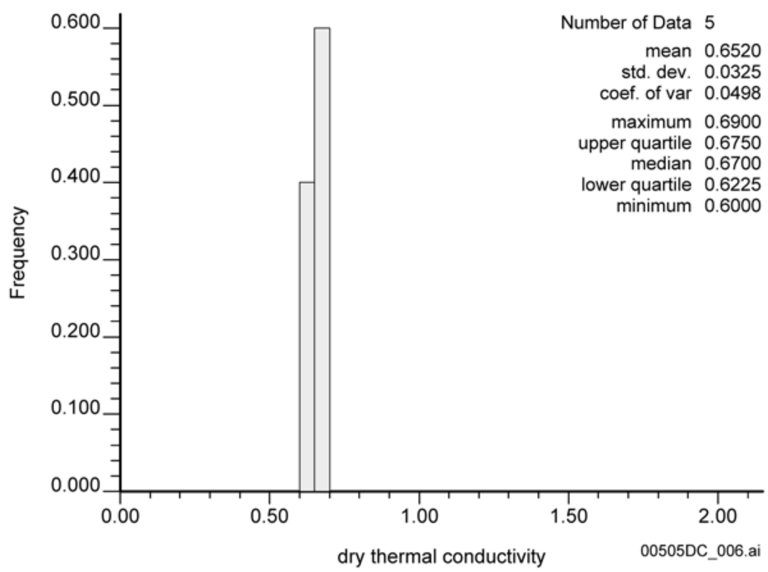
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-13. Validation Non-welded Dry Thermal Conductivity



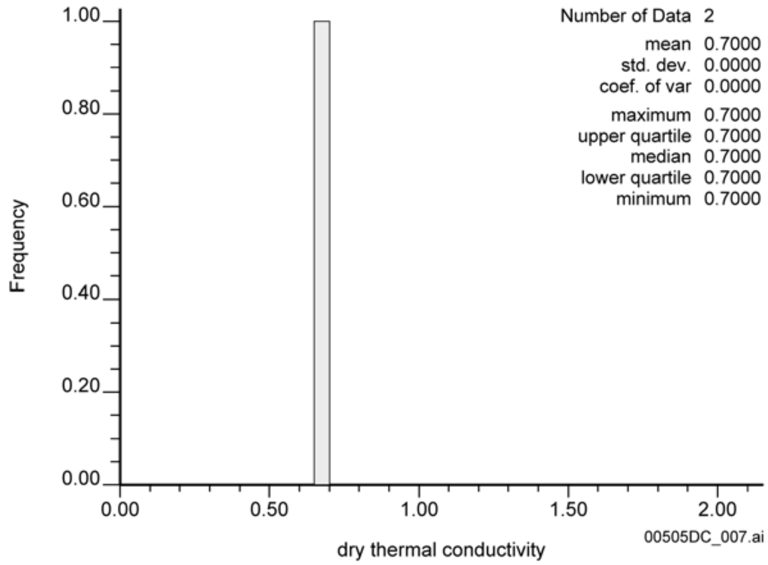
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-14. Validation Calico Hills Dry Thermal Conductivity



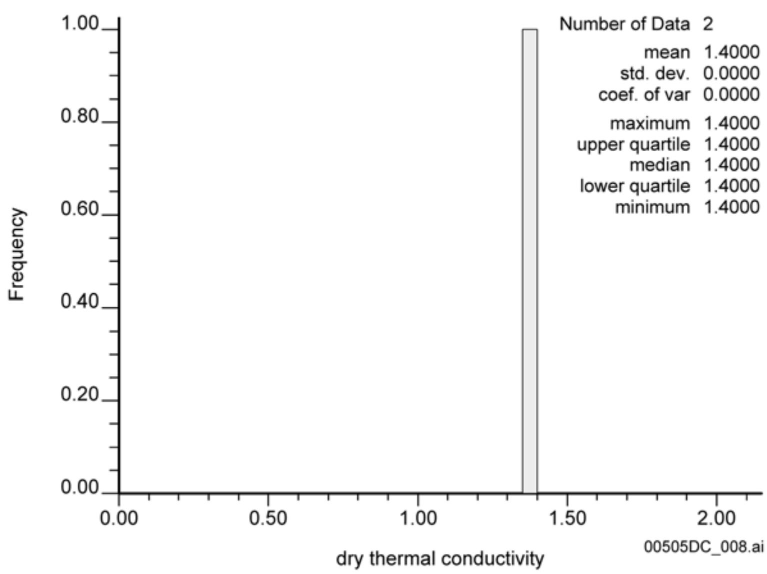
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-15. Validation Prow Pass Non-welded Dry Thermal Conductivity



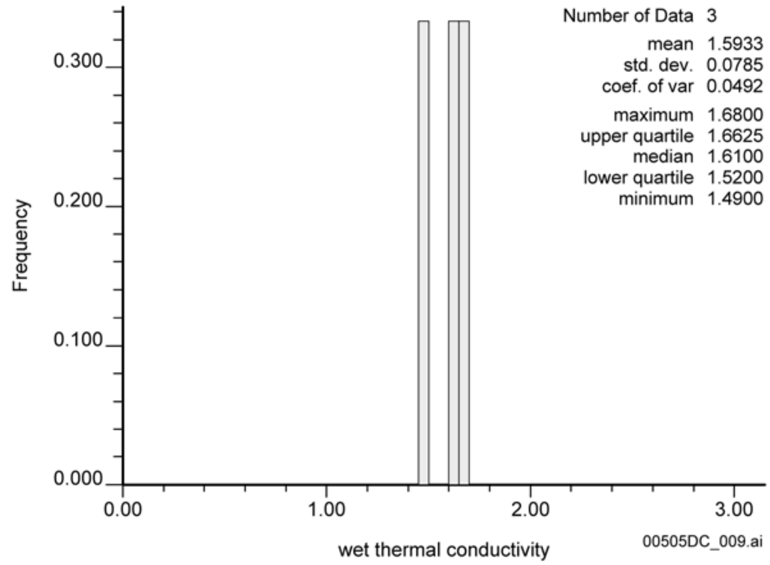
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-16. Validation Bullfrog Non-welded Dry Thermal Conductivity



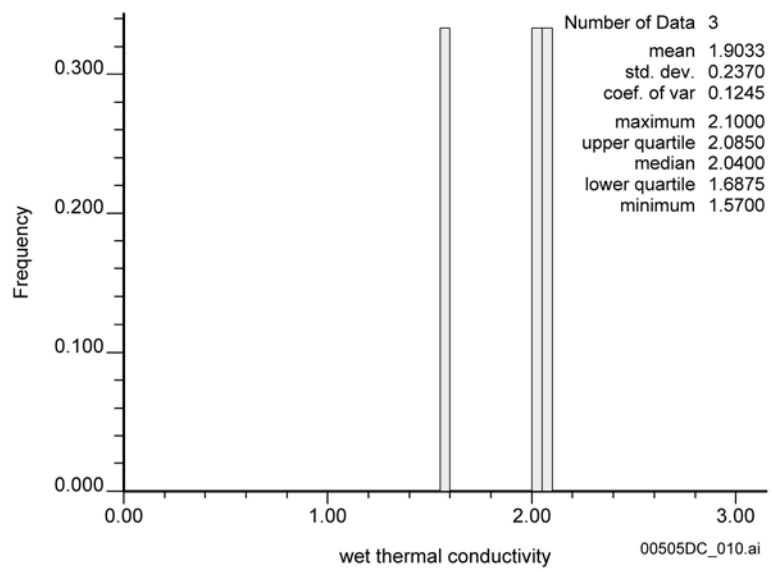
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-17. Validation Bullfrog Welded Dry Thermal Conductivity



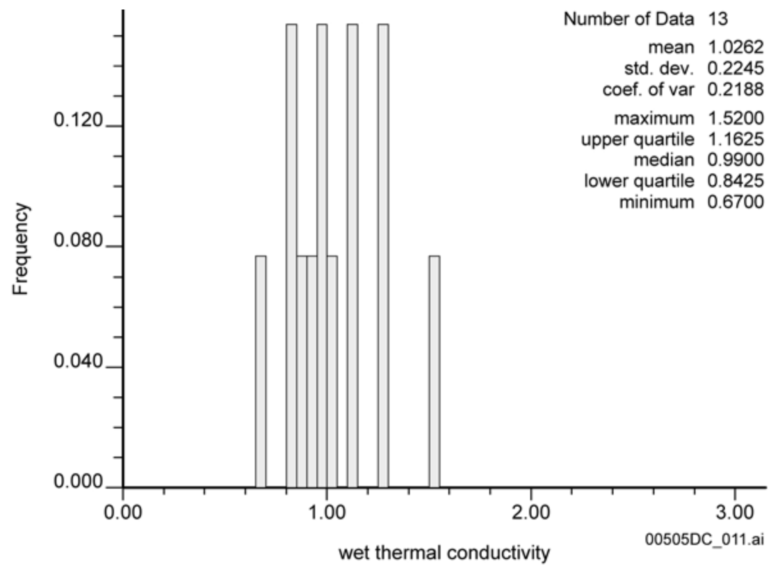
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-18. Validation Welded Wet Thermal Conductivity



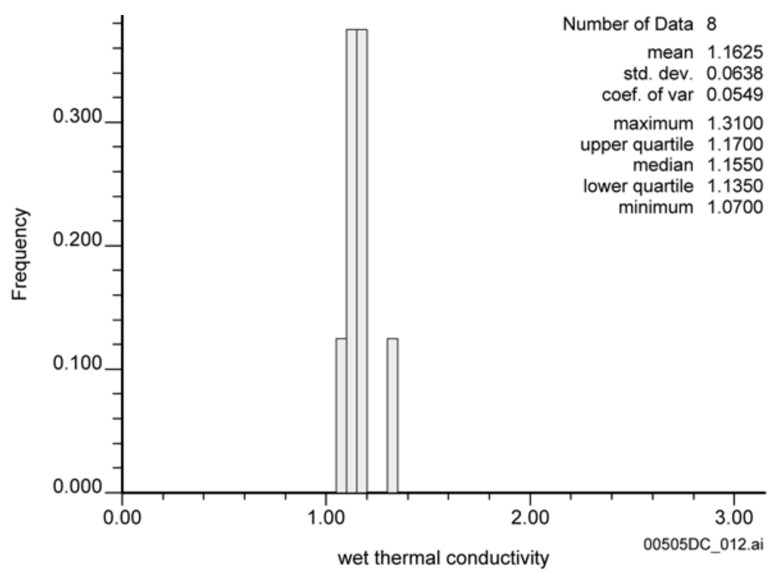
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-19. Validation Vitric Wet Thermal Conductivity



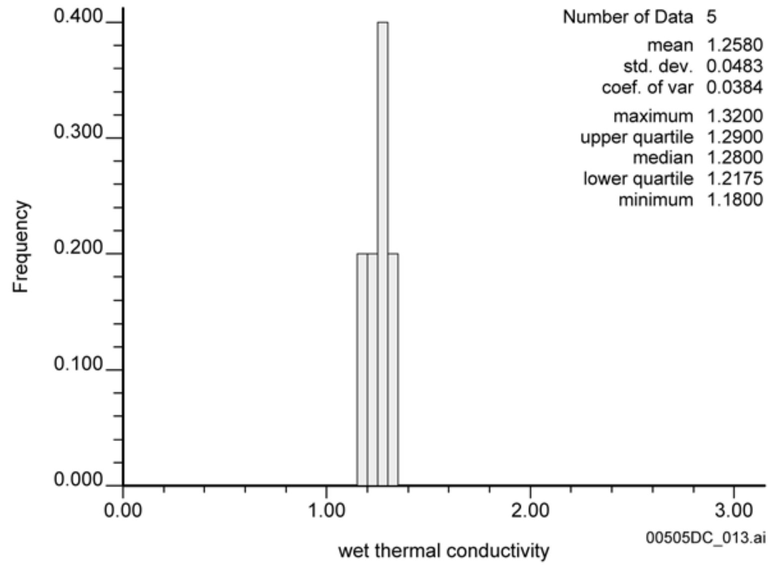
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-20. Validation Non-welded Wet Thermal Conductivity



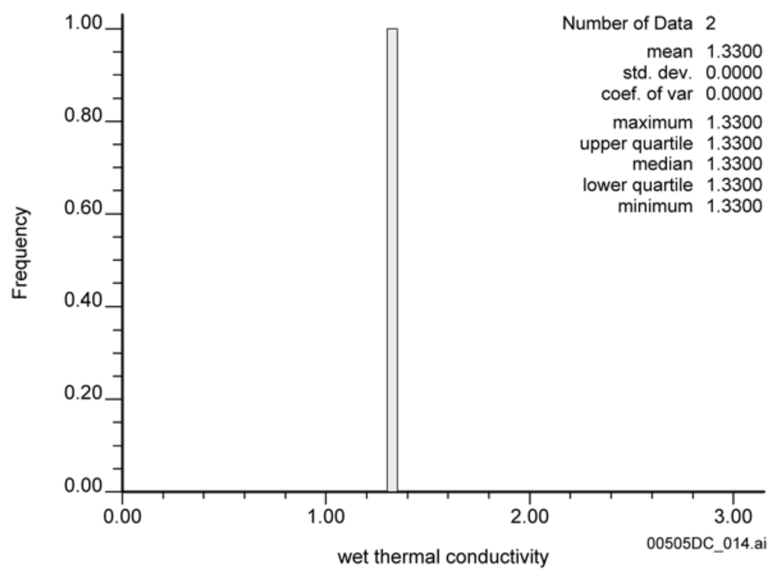
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-21. Validation Calico Hills Wet Thermal Conductivity



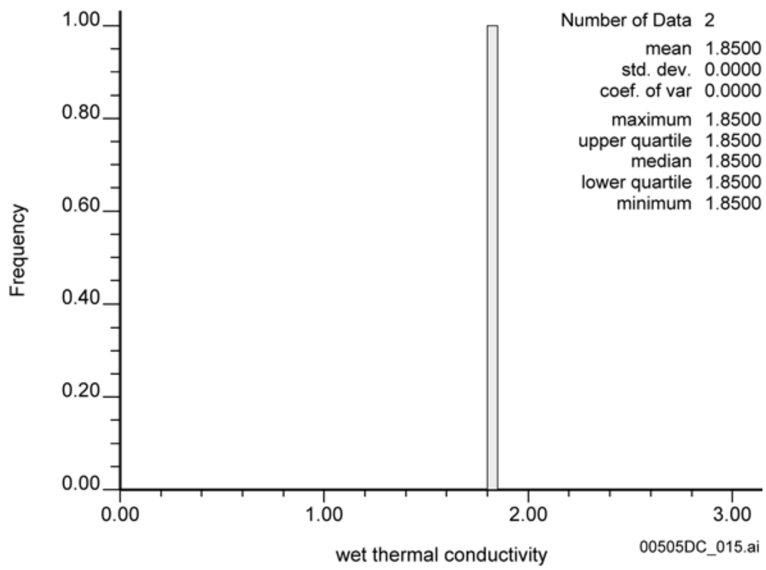
NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-22. Validation Prow Non-welded Wet Thermal Conductivity



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-23. Validation Bullfrog Non-welded Wet Thermal Conductivity



NOTE: This figure was generated by HISTPLT (STN 10802-2.01-00 [DIRS 158223]), using data in Product Output DTN SN0307T0503102.009.

Figure 7-24. Validation Bullfrog Welded Wet Thermal Conductivity

First, a regression was performed to determine the best exponent E for a fit of the form:

$$k = A + \phi_m^{E} \qquad \text{(Eq. 7-3)}$$

where:

k = thermal conductivity
ϕ_m = matrix porosity.

The regression gave an exponent E approximately equal to −1. Using E = −1, a second regression was done on the form $k = A + B/\phi_m + C\,\phi_m^{F}$. The regression gave a value of approximately −2 for the exponent F. Next, using F = −2, two regressions were performed to determine whether adding a bulk density or a grain density term would improve the fit. The grain density term gave a better fit, but because bulk density data are more readily available than grain density data, the grain density term was written as $d_b/(1-\phi_m)$, where d_b is the bulk density. Because the regression form

$$k = A + B/\phi_m + C/\phi_m^2 + D\, d_b/(1-\phi_m) \qquad \text{(Eq. 7-4)}$$

gave fits that were good to within 10 percent of most data points, it was selected as the final form. Thermal conductivity data were fitted to the form (Equation 7-4) by linear regression on columns of data for $1/\phi_m$, $1/\phi_m^2$, and $d_b/(1-\phi_m)$. Here, ϕ_m is the matrix porosity and d_b is the dry bulk density. The dry thermal conductivity (k_d) values give the fit

$$k_d = -1.651 + 0.1802/\phi_m - 4.726^{E-3}/\phi_m^2 + 6.922^{E-4}\, d_b/(1-\phi_m) \qquad \text{(Eq. 7-5)}$$

and the wet thermal conductivity (k_w) values give the fit

$$k_w = -1.207 + 0.1302/\phi_m - 3.323^{E-3}/\phi_m^{\,2} + 8.264^{E-4}\, d_b/(1-\phi_m), \qquad \text{(Eq. 7-6)}$$

where:

d_b is in kg/m^3.

Table 7-2 shows the inputs to and predictions from the dry thermal conductivity regression and Table 7-3 shows the inputs to and predictions from the wet thermal conductivity regression. The relative errors of the fits are shown in the column labeled relerr (relative error). The regression data analysis tool in Excel performs the regression. The Excel spreadsheets for the dry and wet regressions are shown in Appendix Q and Appendix R.

Table 7-2. Regression Fit of Validation Dry Thermal Conductivity

k_d (W/m K)	**$1/\phi$**	**$1/\phi^2$**	**$d_b/(1-\phi)$**	**k_d fit (W/m K)**	**relerr**	**layer**
Inputs:						
1.132	7.812	61.04	2511.	1.207	0.066	welded
1.480	26.32	692.5	2401.	1.481	0.001	vitric
0.417	2.639	6.962	2351.	0.419	0.004	non-welded
0.577	3.546	12.57	2326.	0.538	−0.067	Calico Hills
0.652	3.745	14.03	2442.	0.648	−0.006	Prow Pass non-welded
0.700	4.545	20.66	2410.	0.739	0.055	Bullfrog non-welded
1.400	8.696	75.61	2554.	1.326	−0.053	Bullfrog welded
Root-Mean-Square Error = 0.046						
Coefficients: A= −1.651 B= 0.1802 C= −0.004726 D= 0.0006922						
Predictions:						
	5.155	26.57	2568	0.930	–	Prow Pass welded
	3.472	12.06	2472.	0.629	–	Tram Tuff non-welded
	5.435	29.54	2623.	1.004	–	Tram Tuff welded

NOTE: This table is from the Excel spreadsheet in Appendix Q.
relerr=relative error

Table 7-3. Regression Fit of Validation Wet Thermal Conductivity

k_w (W/m K)	**$1/\phi$**	**$1/\phi^2$**	**$d_b/(1-\phi)$**	**k_w fit (W/m K)**	**relerr**	**layer**
Inputs:						
1.593	7.812	61.04	2511.	1.683	0.056	welded
1.903	26.32	692.5	2401.	1.903	0.000	vitric
1.026	2.639	6.962	2351.	1.056	0.029	non-welded
1.162	3.546	12.57	2326.	1.135	−0.023	Calico Hills
1.258	3.745	14.03	2442.	1.252	−0.005	Prow Pass non-welded

Table 7-3. Regression Fit of Validation Wet Thermal Conductivity (Continued)

k_w (W/m K)	$1/\phi$	$1/\phi^2$	$d_b/(1-\phi)$	k_w fit (W/m K)	relerr	layer
Inputs:						
1.330	4.545	20.66	2410.	1.308	−0.017	Bullfrog non-welded
1.850	8.696	75.61	2554.	1.784	−0.035	Bullfrog welded
Root-Mean-Square Error = 0.030 Coefficients: A= −1.207 B= 0.1302 C= −0.003323 D= 0.0008264						
Predictions:						
	5.155	26.57	2568.	1.498	–	Prow Pass welded
	3.472	12.06	2472.	1.248	–	Tram Tuff non-welded
	5.435	29.54	2623.	1.570	–	Tram Tuff welded

NOTE: This table is from the Excel spreadsheet shown in Appendix R.
relerr=relative error

The maximum relative error is 0.067 for k_d and 0.056 for k_w. The root-mean-square errors are approximately 0.046 for k_d and 0.030 for k_w. These fits give the thermal conductivity values used in Table 7-5 and Table 7-6 for Prow Pass welded, Tram Tuff non-welded, and Tram Tuff welded. Note that in the comparison of the t statistic (Equation 7-1) based upon the normalized difference in the means, the combined variance is used to calculate the standard deviations from the two distributions. Because the number of data points is limited to seven (one for each layer of the original data), the standard deviation was set to zero. This has the effect of increasing the t statistic in Equation 7-1 by reducing S in Equation 7-2, and provides a more severe Student t test statistic for accepting the test hypothesis (that the means are derived from the same distribution) than would be the case if the standard deviation was set to a nonzero value.

To reproduce the computer calculations, Excel spreadsheets *drytcregression.xls* and *wettcregression.xls* are prepared in subdirectory Outputs\TCRegression using the inputs parts of the data in Table 7-2 and Table 7-3. The Tools menu is selected in Excel, then the Data Analysis menu is selected, followed by the Regression option. The input Y range is column B of the spreadsheet ($B$2:$B$8), the thermal conductivity values. The input X range is cells E2 through G8. Excel performs the regression and puts the resulting coefficients in the Coefficients column of a worksheet. The Intercept line is the constant A in Equation 7-4. The next three rows give the B, C, and D coefficients.

7.2.3 Validation of the Thermal Conductivity Part of the Model

All qualified, verified thermal conductivity data not used in the model development are used to validate the thermal conductivity model. The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file in Appendix O collects the thermal conductivity data from two SEP data tables, and puts the data into a single file. The REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input control file in Appendix P separates the thermal conductivity data from this one file into 10 files, one for each geologic rock type. The Student's t coefficients (Beyer 1987 [DIRS 103805]) for one-sided 0.975 confidence (0.025 out of confidence on each side, or 95-percent confidence) and one-sided 0.99 confidence (0.01 out of confidence on each side, or 98-percent confidence) values are shown in Table 7-4 for the number of degrees of freedom $\nu = N_1 + N_2 - 2$. Because there are only two endpoint model values for the solid thermal conductivity of the vitric rock types, the number of data values for N_1 was set at two.

The numbers of points, means, and standard deviations shown in Figures 7-11 to 7-17 provide dry thermal conductivity data for the columns headed N_2, μ_2, and s_2 in Table 7-5 for the welded, vitric, non-welded, calico, Prow Pass non-welded, Bullfrog non-welded and Bullfrog welded layers. The linear regression in Table 7-2 provides dry thermal conductivity values for the Prow Pass welded, Tram Tuff non-welded and Tram Tuff welded layers. Standard deviations are not available from the regression and are conservatively taken as 10 percent of the mean values. The standard deviations of the 7 wet and 7 dry input values average more than 10 percent of the means, so the 10-percent choice for the regression standard deviations is somewhat conservative.

The dry thermal conductivity validation is shown in Table 7-5. Columns S_1 and S_2 are calculated as sqrt (N_1) multiplied by s_1 and sqrt (N_2) multiplied by s_2. Column $s_{combined}$ is computed using Equation 7-2. Column t is computed from Equation 7-1. All of the normalized differences of the means are smaller in magnitude than the corresponding critical values in Table 7-4, so the means show no statistically significant difference at the 95- or 98-percent significance levels.

Table 7-4. Student's t-Distribution Critical Values at Various Confidence Levels

Type	Rock Type	Degrees of Freedom (ν)	Critical Value for Significance Level at:	
			95%	98%
dry	welded	60	2.000	2.390
dry	vitric	3	3.182	N/A
dry	non-welded	38	2.025	N/A
dry	Calico Hills	11	2.201	N/A
dry	Prow Pass non-welded	12	2.179	N/A
dry	Prow Pass welded	22	2.074	N/A
dry	Bullfrog non-welded	9	2.262	N/A
dry	Bullfrog welded	17	2.110	N/A
dry	Tram Tuff non-welded	14	2.145	N/A
dry	Tram Tuff welded	22	2.074	N/A
wet	welded	18	2.101	N/A
wet	vitric	3	3.182	4.541
wet	non-welded	20	2.086	N/A
wet	Calico Hills	11	2.201	N/A
wet	Prow Pass non-welded	12	2.179	N/A
wet	Prow Pass welded	22	2.074	N/A
wet	Bullfrog non-welded	9	2.262	N/A
wet	Bullfrog welded	17	2.110	N/A
wet	Tram Tuff non-welded	14	2.145	2.624
wet	Tram Tuff welded	22	2.074	N/A

NOTES: Critical values come from Beyer (1987 [DIRS 103805], p. 571).
N/A =not applicable.

Table 7-5. Validation of the Dry Matrix Thermal Conductivity Model

Layer	Model Thermal Conductivity (W/m K)				Validation Thermal Conductivity (W/m K)				ν	$s_{combined}$	t	t for significance level at:	
	N_1	mean	s_1	S_1	N_2	mean	s_2	S_2				95%	98%
welded	17	1.300	0.231	0.952	45	1.132	0.268	1.800	60	0.263	2.241	2.000	2.390
vitric	2	0.688	0.229	0.324	3	1.480	0.327	0.566	3	0.377	−2.304	3.182	N/A
non-welded	9	0.490	0.158	0.474	31	0.417	0.160	0.889	38	0.163	1.183	2.025	N/A
Calico Hills	5	0.595	0.112	0.250	8	0.578	0.053	0.150	11	0.088	0.349	2.201	N/A
Prow Pass non-welded	9	0.569	0.104	0.312	5	0.652	0.033	0.073	12	0.092	−1.609	2.179	N/A
Prow Pass welded	17	1.060	0.183	0.755	7	0.930	0.093	0.246	22	0.169	1.711	2.074	N/A
Bullfrog non-welded	9	0.658	0.130	0.390	2	0.700	0.000	0.000	9	0.130	−0.413	2.262	N/A
Bullfrog welded	17	1.300	0.239	0.985	2	1.400	0.000	0.000	17	0.239	−0.560	2.110	N/A
Tram Tuff non-welded	9	0.535	0.106	0.318	7	0.629	0.063	0.166	14	0.096	−1.945	2.145	N/A
Tram Tuff welded	17	1.060	0.183	0.755	7	1.004	0.100	0.266	22	0.171	0.731	2.074	N/A

NOTES: This table was generated by using data from Table 6-13, Table 7-2, Figure 7-11 to Figure 7-17, and Equation 7-1 and Equation 7-2.

N/A = Not applicable.

Figure 7-18 to Figure 7-24 provide the numbers of points, means, and standard deviations for the wet thermal conductivity data in the welded, vitric, non-welded, calico, Prow Pass non-welded, Bullfrog non-welded and Bullfrog welded layers for the columns headed N_2, μ_2, and s_2 in Table 7-6. The linear regression in Table 7-3 provides the wet thermal conductivity values for the Prow Pass welded, Tram Tuff non-welded and Tram Tuff welded layers. Standard deviations are not available from the regression and are taken as 10 percent of the mean values.

The wet thermal conductivity validation is shown in Table 7-6. Columns S_1 and S_2 are calculated as sqrt (N_1) multiplied by s_1 and sqrt (N_2) multiplied by s_2. Column $s_{combined}$ is computed using Equation 7-2. Column t is computed from Equation 7-1. All of the normalized differences of the means are smaller in magnitude than the corresponding critical values in Table 7-4, so the means show no statistically significant difference. In terms of thermal conductivity, the model meets the 95- or 98-percent confidence criteria (BSC 2004 [DIRS 171708]), and is validated for its intended use.

Table 7-6. Validation of the Wet Matrix Thermal Conductivity Model

Layer	Model Thermal Conductivity (W/m K)				Validation Thermal Conductivity (W/m K)				ν	$s_{combined}$	t	t for significance level:	
	N_1	mean	s_1	S_1	N_2	mean	s_2	S_2				95%	98%
welded	17	1.810	0.195	0.804	3	1.593	0.079	0.136	18	0.192	1.800	2.101	N/A
vitric	2	0.796	0.251	0.355	3	1.903	0.237	0.410	3	0.313	−3.871	3.182	4.541
non-welded	9	1.060	0.146	0.438	13	1.026	0.225	0.809	20	0.206	0.379	2.086	N/A
Calico Hills	5	1.260	0.141	0.315	8	1.163	0.064	0.180	11	0.110	1.561	2.201	N/A
Prow Pass non-welded	9	1.130	0.117	0.351	5	1.258	0.048	0.108	12	0.106	−2.165	2.179	N/A
Prow Pass welded	17	1.630	0.168	0.693	7	1.498	0.150	0.396	22	0.170	1.728	2.074	N/A
Bullfrog non-welded	9	1.190	0.138	0.414	2	1.330	0.000	0.000	9	0.138	−1.298	2.262	N/A
Bullfrog welded	17	1.810	0.198	0.816	2	1.850	0.000	0.000	17	0.198	−0.270	2.110	N/A
Tram Tuff non-welded	9	1.100	0.116	0.348	7	1.248	0.125	0.330	14	0.128	−2.291	2.145	2.624
Tram Tuff welded	17	1.630	0.168	0.693	7	1.570	0.157	0.415	22	0.172	0.776	2.074	N/A

NOTES: This table was generated by using data from Table 6-13, Table 7-3, Figure 7-18 to Figure 7-24, and Equation 7-1 and Equation 7-2.

N/A = Not applicable.

7.2.4 Maximum Relative Errors In the Model Thermal Conductivity Values

There are two ways to determine the limits of validity of the model. One way to estimate the errors in the model thermal conductivity values is to use the standard deviations of the model data (Table 6-13) with (two-sided) 95- or 98-percent confidence limits from Student's t-distribution. The (one-sided) 0.975 or 0.99 values for the numbers of model data points are shown in Table 7-7, along with the means and standard deviations from Table 6-13. Because Student's t-distribution is symmetrical, the one-sided 0.975 and 0.99 values are equivalent to the two-sided 95- and 98-percent confidence values, respectively.

The other way to determine the limits of validity of the model is to estimate the maximum possible relative errors in the thermal conductivity that allow validation from the limits on the validation restriction on the difference of the means:

$$| \mu_1 - \mu_x | / s_{combined} = t_{critical} \qquad \text{(Eq. 7-7)}$$

Here, μ_1 is the model mean and μ_x is the maximum or minimum value at which the normalized difference in the means equals the critical value ($t_{critical}$) from Student's t-distribution. The minimum and maximum values are the limits that the validation thermal conductivity could have had and still show that the model mean is valid. The maximum relative error E is:

$$E = | \mu_1 - \mu_x | / \mu_1 = t_{critical}\, s_{combined} / \mu_1 \qquad \text{(Eq. 7-8)}$$

Table 7-8 gives the maximum relative errors calculated from Equation 7-8 using the values in Table 7-4, Table 7-5, and Table 7-6.

Table 7-7. Percent Relative Errors in Thermal Conductivity Data Based on Standard Deviations

		Dry Matrix Thermal Conductivity (W/m K)					Wet Matrix Thermal Conductivity (W/m K)				
Layer	**N**	**Confidence Level**	**T for ν = N−1**	**mean**	**s**	**% Relative Error**	**Confidence Level**	**T for ν = N−1**	**mean**	**s**	**% Relative Error**
welded	17	98%	2.583	1.300	0.231	46	95%	2.120	1.810	0.195	23
vitric	2	95%	12.706	0.688	0.229	423	98%	31.821	0.796	0.251	1003
non-welded	9	95%	2.306	0.490	0.158	74	95%	2.306	1.060	0.146	32
Calico Hills	5	95%	2.776	0.595	0.112	52	95%	2.776	1.260	0.141	31
Prow Pass non-welded	9	95%	2.306	0.569	0.104	42	95%	2.306	1.130	0.117	24
Prow Pass welded	17	95%	2.120	1.060	0.183	37	95%	2.120	1.630	0.168	22
Bullfrog non-welded	9	95%	2.306	0.658	0.130	46	95%	2.306	1.190	0.138	27
Bullfrog welded	17	95%	2.120	1.300	0.239	39	95%	2.120	1.810	0.198	23
Tram Tuff non-welded	9	95%	2.306	0.535	0.106	46	98%	2.896	1.100	0.116	31
Tram Tuff welded	17	95%	2.120	1.060	0.183	37	95%	2.120	1.630	0.168	22

NOTES: Columns N, mean, and s are taken from Table 6-13.
Column T is taken from Beyer (1987 [DIRS 103805], p. 571).
Percent Relative Error = 100 × s × T/mean.

Table 7-8. Percent Relative Errors of the Model Thermal Conductivity Values from Validation Limits

Layer	Dry Matrix Thermal Conductivity (W/m K)						Wet Matrix Thermal Conductivity (W/m K)					
	ν	**Confidence Level**	**$T_{critical}$**	**mean**	**$s_{combined}$**	**% Relative Error**	**ν**	**Confidence Level**	**$T_{critical}$**	**mean**	**$s_{combined}$**	**% Relative Error**
welded	60	98%	2.390	1.300	0.263	48	18	95%	2.101	1.810	0.192	22
vitric	3	95%	3.182	0.688	0.377	174	3	98%	4.541	0.796	0.313	179
non-welded	38	95%	2.025	0.490	0.163	68	20	95%	2.086	1.060	0.206	40
Calico Hills	11	95%	2.201	0.595	0.088	33	11	95%	2.201	1.260	0.110	19

Table 7-8. Percent Relative Errors of the Model Thermal Conductivity Values from Validation Limits (Continued)

Layer	Dry Matrix Thermal Conductivity (W/m K)						Wet Matrix Thermal Conductivity (W/m K)					
	ν	Confidence Level	$T_{critical}$	mean	$s_{combined}$	% Relative Error	ν	Confidence Level	$T_{critical}$	mean	$s_{combined}$	% Relative Error
Prow Pass non-welded	12	95%	2.179	0.569	0.092	35	12	95%	2.179	1.130	0.106	20
Prow Pass welded	22	95%	2.074	1.060	0.169	33	22	95%	2.074	1.630	0.170	22
Bullfrog non-welded	9	95%	2.262	0.658	0.130	45	9	95%	2.262	1.190	0.138	26
Bullfrog welded	17	95%	2.110	1.300	0.239	39	17	95%	2.110	1.810	0.198	23
Tram Tuff non-welded	14	95%	2.145	0.535	0.096	38	14	98%	2.624	1.100	0.128	31
Tram Tuff welded	22	95%	2.074	1.060	0.171	33	22	95%	2.074	1.630	0.172	22

NOTES: The input data in this table are taken from Table 7-4, Table 7-5, and Table 7-6.
Percent Relative Error = 100 × $s_{combined}$ × $T_{critical}$ /mean (see Equation 7-8).

Because these two methods give different limits, the smaller value must be taken from Table 7-7 and Table 7-8 to maintain the validity of the model. These values are shown in Table 7-9, which represent the actual limits on the model for the model to be valid.

Table 7-9. Maximum Relative Errors of the Model Thermal Conductivity Values

Layer	Maximum Relative Error (percent)	
	Dry Matrix Thermal Conductivity	Wet Matrix Thermal Conductivity
welded	46	22
vitric	174	179
non-welded	68	32
Calico Hills	33	19
Prow Pass non-welded	35	20
Prow Pass welded	33	22
Bullfrog non-welded	45	26
Bullfrog welded	39	23
Tram Tuff non-welded	38	31
Tram Tuff welded	33	22

NOTE: The data in this table are the minimum values from Table 7-7 and Table 7-8.

7.3 VALIDATION SUMMARY

The *Thermal Conductivity of Non-Repository Lithostratigraphic Layers* model has been validated by applying acceptance criteria based on an evaluation of the relative importance of the model to the potential performance of the repository system. All validation requirements defined in TWP-MGR-PA-000019 REV 00 ICN 01 (BSC 2004 [DIRS 171708], Section 2.2.2) have been fulfilled, including corroboration of model results with qualified thermal conductivity data. Requirements for confidence building during model development have also been satisfied. The model development activities and post-development validation activities described in this report establish the scientific bases for the Thermal Conductivity of Non-Repository Lithostratigraphic Layers Model. Based on this, the model and results are considered to be sufficiently accurate and adequate for the intended purpose and to the level of confidence required by the relative importance of the model to the potential performance of the repository system.

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8. CONCLUSIONS

8.1 SUMMARY

The thermal conductivity model is developed using 31 sets of dry and wet thermal conductivity values, and approximately 1,900 porosity measurements. The data triads are processed by the inverse program HSUINV (STN 10804-1.0-00 [DIRS 158228]) to produce 31 sets of porosity, solid thermal conductivity, and a geometric parameter. Distributions are estimated from these data for the welded, non-welded, and calico rock types. In the absence of any vitric rock-type data, the distribution for solid thermal conductivity is assumed to be the handbook range for solid glass and the geometric parameter is assumed to be one. The distributions are used as input to the GENHSUMODELDATA (STN 10905-1.0-00 [DIRS 162671]) to produce average values and standard deviations for dry and wet thermal conductivity and for porosity. The dry and wet thermal conductivities and porosities presented in Table 6-13 are the final model of values for the nonrepository layers of the GFM of Yucca Mountain from Crystal-Rich Tiva/Post Tiva down through the Tram Tuff non-welded layer, Trambt (Appendix U). The results in Table 6-13 are available as Output DTN SN0303T0503102.008. The input and output data used in this model development are available as Product Output DTN SN0307T0503102.009.

The model is validated using 356 thermal conductivity values and approximately 10,000 porosity values. The standard deviations on the model are moderately large, varying from 10 percent to 33 percent of the mean. Because the number of data points used in model development is small, confidence intervals are found using Student's t-distribution rather than the normal distribution. Measurement uncertainties are small compared to 95- and 98-percent confidence intervals and, therefore, are not included in the calculations. The Prow Pass welded, Tram Tuff welded, and Tram Tuff non-welded rock types lack dry or wet thermal conductivity data for the validation, so the values for the other seven rock types are fitted by linear regression to predict values for these three rock types. The form used (Equation 7-4 from Section 7.2 of this report) is:

$$k = A + B/\phi_m + C/\phi_m^2 + D\, d_b/(1-\phi_m)$$

where:

A, B, C, and D are the regression coefficients
k = thermal conductivity
ϕ_m = matrix porosity
d_b = dry bulk density.

The fits of the validation thermal conductivities have maximum relative errors of less than seven percent. The means of the model and validation dry and wet thermal conductivities are compared using Student's t-distribution, and the differences in the means are not statistically significant at the 95- or 98-percent confidence level. This constitutes validation of the vitric rock assumption and the thermal conductivity model at the 95- or 98-percent confidence level.

The means of the model and model validation porosity data are compared in a similar manner and are found to be statistically equivalent. This validates the assumption that the approximately

1,900 model porosity values are representative of the remaining 10,000 model validation porosity values.

8.2 YUCCA MOUNTAIN REVIEW PLAN CRITERIA ASSESSMENT

The model developed in this report addresses the *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) acceptance criteria.

8.2.1 Acceptance Criterion 2 – Data Are Sufficient for Model Justification

(1) Geological, hydrological, and geochemical values used in the license application are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided.

Basis: Qualified, site-specific data obtained from core sample measurements are used to develop the geostatistical models of porosity and thermal conductivity. The input data and their appropriateness in model selection and development are described in Sections 4.1 and 6.1 respectively. Adequate descriptions of how the data were used, interpreted, and synthesized into the developed parameters are included in Section 6 and Appendices B through R.

8.2.2 Acceptance Criterion 3 – Data Uncertainty Is Characterized and Propagated Through the Model Abstraction

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

Basis: The input data described in Section 4.1 and used in the model development activities described in Section 6 are representative of the nonrepository lithostratigraphic layers. The data are technically defensible because they were obtained from Project qualified and controlled sources. Measurement errors (see Appendix A), biases, and natural sample variabilities are propagated into the models that use these data. Therefore, the approach used to develop the output of this report reasonably accounts for uncertainties and variabilities and does not result in an under representation of the risk estimate.

(2) Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the total system performance assessment calculations of quantity and chemistry of water contacting engineered barriers and waste forms are technically defensible and reasonable, based on data from the Yucca Mountain region (e.g., results from large block and drift-scale heater and niche tests), and a combination of techniques that may include laboratory experiments, field measurements, natural analog research, and process-level modeling studies.

Basis: The validation of the thermal conductivity and porosity models, as described in Section 7, is based on corroboration with data from laboratory and field experiments involving the nonrepository units characterized in this report. These validation and confidence building exercises provide justification that the models are technically defensible, reasonable and support the use of these models as input to other process-level models in the Total System Performance Assessment (TSPA) for the License Application (LA).

The justification for the values used is addressed in Section 4.1. The use of natural analogue data (solid glass) as an approximation of vitric, densely welded properties is addressed in Section 5, Assumption 2, and is justified in Section 7.2.3. The suitability of data for use in the Hsu model is discussed in Section 6.3. The estimation of probability distributions for data is described in Sections 6.4, 6.5, and 6.6. Estimates of measurement uncertainty in the data are discussed in Sections 6.2 and 6.6. The numerical uncertainties in averages of data are addressed in Sections 7.2.1, 7.2.3, and 7.2.4. The maximum uncertainties in model results are evaluated in Section 7.2.4.

8.2.3 Acceptance Criterion 4 – Model Uncertainty is Characterized and Propagated Through the Model Abstraction

(2) Alternative modeling approaches are considered and the selected modeling approach is consistent with available data and current scientific understanding. A description that includes a discussion of alternative modeling approaches not considered in the final analysis and the limitations and uncertainties of the chosen model is provided.

Basis: Alternative conceptual models of thermal conductivity are discussed in Section 6.1. The rationale used in the model selection process is consistent with the data available for model development and the intended use of the models. The limitations of these models are discussed in Section 6.1. The appropriateness of the selected models is confirmed through the validation and confidence building exercises described in Section 7.

8.3 ADDITIONAL SENSITIVITY ANALYSIS

The *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]) evaluates repository temperatures based upon the uncertainty in thermal conductivity of the main repository units based upon the mean and standard deviation of these units as developed in *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854]). This uncertainty is propagated to the TSPA-LA. The following discussion addresses the issue of propagating the uncertainty for thermal conductivity for the nonrepository horizon units and provides a justification for not propagating uncertainty for these units to the TSPA-LA.

An analysis (Appendix S) was performed to assess the significance of the nonrepository horizon units on the uncertainty in repository temperature over extended periods of time (20,000 years). The analysis utilized the steady-state heat transfer by heat conduction in the vertical direction. Both the thermal conductivity under saturated conditions of the repository and nonrepository horizon units are included in this analysis. The analysis predicts an approximate peak uncertainty in temperature of 7 degrees C. This uncertainty decreases with time after closure due to a decrease in average repository heat loading over this period. An uncertainty analysis utilizing Hahn and Shapiro (1967 [DIRS 146529], p. 231) was performed and predicted that the Tsw38 layer (Tptpv3) below the repository provides the most significant contribution to uncertainty over extended periods. This is because the rock mass thermal conductivity of this unit is much lower (0.8 W/(m K)) than the repository horizon unit (1.89 W/(m K)) under saturated conditions.

The steady state analysis tends to overestimate the uncertainty of the nonrepository units because in reality, heat diffuses more slowly from the repository horizon. The results of calculations in the *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]) show that, immediately after closure, the variations in repository temperature, and therefore waste package temperature, are dominated by the uncertainty at the repository horizon, because heat has not diffused very far from the repository horizon at the time the peak waste package temperature is reached. At later times, the steady state analysis in Appendix S indicates that Tsw38 is more dominant; however, at later times, the uncertainty in repository temperatures is low and need not be considered in the TSPA-LA.

9. REFERENCES

The following is a list of the references cited in this document. Column 2 represents the unique six digit numerical identifier (the Document Input Reference System number), which is placed in the text following the reference callout (e.g., BSC 2004 [DIRS 168489]). The purpose of these numbers is to assist in locating a specific reference. Multiple sources by the same author (e.g., BSC 2004) are sorted alphabetically by title.

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SNF40060298001.001. Unsaturated Zone Lithostratigraphic Contacts in Borehole USW SD-6. Submittal date: 10/15/1998. 107372

SNL01A05059301.002. Thermal Conductivity Data from USW NRG-6 Drillhole Samples from Depth of 28.8 ft. to 987.0 ft. Submittal date: 07/15/1994. 150042

SNL01A05059301.005. Laboratory Thermal Conductivity Data for Boreholes UE25 NRG-4, NRG-5; USW NRG-6 and NRG-7/7A. Submittal date: 02/07/1996. 109002

SNL01A05059301.007. Calculated Porosities for Thermal Conductivity Specimens from Boreholes UE25 NRG-4, UE25 NRG-5, USW NRG-6, and USW NRG-7/7a. Submittal date: 10/14/1998. 108980

SNL02030193001.001. Mechanical Properties Data for Drillhole USW NRG-6 Samples from Depth 22.2 ft. to 328.7 ft. Submittal date: 05/17/1993. 120572

SNL02030193001.002. Mechanical Properties Data for Drillhole USW NRG-6 Samples from Depth 22.2 ft. to 427.0 ft. Submittal date: 06/25/1993. 120575

SNL02030193001.003. Mechanical Properties Data for Drillhole UE-25 NRG-2 Samples from Depth 150.5 ft. to 200.0 ft. Submittal date: 07/07/1993. 120578

SNL02030193001.004. Mechanical Properties Data for Drillhole USW NRG-6 Samples from Depth 462.3 ft. to 1085.0 ft. Submittal date: 08/05/1993. 108415

SNL02030193001.005. Mechanical Properties Data for Drillhole UE-25 NRG#3 Samples from Depth 15.4 ft. to 297.1 ft. Submittal date: 09/23/1993. 122545

SNL02030193001.006. Mechanical Properties Data for Drill Hole UE-25 NRG#2A Samples from Depth 90.0 ft. to 254.5 ft. Submittal date: 10/13/1993. 120579

SNL02030193001.007. Mechanical Properties Data for Drill Hole UE-25 NRG#3 Samples from Depth 263.3 ft. to 265.7 ft. Submittal date: 10/20/1993. 120582

SNL02030193001.008. Mechanical Properties Data for Drill Hole USW NRG-6 Sample 416.0 ft. Submittal date: 10/20/1993. 120597

SNL02030193001.009. Mechanical Properties Data for Drillhole UE25 NRG-5 Samples from Depth 781.0 ft. to 991.9 ft. Submittal date: 11/18/1993. 109614

SNL02030193001.012. Mechanical Properties Data for Drillhole UE25 NRG-5 Samples from Depth 847.2 ft. to 896.5 ft. Submittal date: 12/02/1993. 108416

SNL02030193001.013. Mechanical Properties Data for Drillhole UE25 NRG-2B Samples from Depth 2.7 ft. to 87.6 ft. Submittal date: 12/02/1993. 120614

SNL02030193001.014. Mechanical Properties Data for Drillhole UE25 NRG-4 Samples from Depth 378.1 ft. to 695.8 ft. Submittal date: 01/31/1994. 109609

SNL02030193001.015. Mechanical Properties Data for Drillhole UE25 NRG-4 Samples from Depth 527.0 ft. Submittal date: 02/16/1994. 120617

SNL02030193001.016. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 18.0 ft. to 472.9 ft. Submittal date: 03/16/1994. 120619

SNL02030193001.017. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 18.0 ft. to 495.0 ft. Submittal date: 03/21/1994. 109610

SNL02030193001.018. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 344.4 ft. Submittal date: 04/11/1994. 109611

SNL02030193001.019. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 507.4 ft. to 881.0 ft. Submittal date: 06/29/1994. 108431

SNL02030193001.020. Mechanical Properties Data for Drillhole USW NRG-7/7A Samples from Depth 554.7 ft. to 1450.1 ft. Submittal date: 07/25/1994.	108432
SNL02030193001.021. Mechanical Properties Data (Ultrasonic Velocities, Static Elastic Properties, Triaxial Strength, Dry Bulk Density & Porosity) for Drillhole USW NRG-7/7A Samples from Depth 345.0 ft. to 1408.6 ft. Submittal date: 02/16/1995.	108433
SNL02030193001.022. Mechanical Properties Data for Drill Hole USW NRG-6 Samples from Depth 5.7 ft. to 1092.3 ft. Submittal date: 02/27/1995.	109613
SNL02030193001.028. Confined Compression Experiments at 150 Degrees C on TSW2 from Borehole USW SD-9. Submittal date: 09/05/1996.	159972
SNL03042594001.002. Average Grain Density for Thermal Properties Test Samples from Boreholes UE25 NRG-4, UE25 NRG-5, and USW NRG-6. Submittal date: 06/20/1994.	109607
SNL03042594001.003. Average Grain Density for Thermal Properties Test Samples from Borehole UE25 NRG-7/7A. Submittal date: 06/20/1994.	109608
SNL22100196001.006. Laboratory Measurements of Thermal Conductivity as a Function of Saturation State for Welded and Nonwelded Tuff Specimens. Submittal date: 06/08/1998.	158213

9.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

SN0303T0503102.008. Revised Thermal Conductivity of the Non-repository Layers of Yucca Mountain. Submittal date: 03/19/2003.

SN0307T0503102.009. Thermal Conductivity Model for the Non-repository Layers of Yucca Mountain. Submittal date: 07/21/2003.

9.5 SOFTWARE CODES

SNL 2002. *Software Code: GENHSUMODELDATA.* V1.0. PC/Windows 2000 Server. 10905-1.0-00.	162671
SNL 2002. *Software Code: GSLIB HISTPLT.* V2.01. 10802-2.01-00.	158223
SNL 2002. *Software Code: HSUINV.* V.1.0. PC/Windows 2000 Server. 10804-1.0-00.	158228
SNL 2002. *Software Code: REFORMAT.* V2.0. PC/Windows 2000 Server. 10907-2.0-00.	162673
SNL 2002. *Software Code: SPLICE.* V1.0. PC/Windows 2000 Server. 10906-1.0-00.	162672

APPENDIX A

ESTIMATES OF MEASUREMENT UNCERTAINTIES IN THERMAL CONDUCTIVITY, MATRIX POROSITY, AND DRY BULK DENSITY

-----Original Message-----
From: Brodsky, Nancy
Sent: Tuesday, July 29, 2003 4:06 PM
To: Iuzzolino, Harold Joseph
Cc: Castagna, Iris J
Subject: Uncertainty Estimates

Harold:

The error in matrix thermal conductivity for oven-dried specimens is plus/minus 5 percent of the measured value. This is the error associated with the NIST standards used for calibration, and it is the minimum error associated with the guarded heat flow method (GHFM).

For saturated specimens, 5 percent has also always been the error specified by the equipment manufacturer. As documented in Laboratory Measurements of Thermal Conductivity as a Function of Saturation State for Welded and Nonwelded Tuff Specimens, ACC: MOL.19980901.0177, on page 21, I have suspected it might be higher for saturated specimens, but there is no solid qualified data at this time to provide any alternative error value.

Matrix porosity - This depends on the method used in the calculation. A lot of laboratory methods report about 1 percent error - that's 1 percent porosity, not 1 percent of the measured porosity. A realistic assessment might come from comparing porosities calculated using dry bulk densities and grain densities, as opposed to calculated using dry and saturated porosities. I did this on the attached spreadsheet - see column O. In some cases, the errors are higher than 1 percent.

Dry bulk density - this is mass divided by specimen volume. Mass is usually measured to 0.01g; volume is calculated from diameter and length measurements, usually accurate to 0.001 inches. This is then converted to metric, probably using a conversion factor of 3 significant digits.

- Nancy

Poros_tc_addcalc.xls

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Calculation of porosities from dry bulk and grain densities, and from saturated and dry bulk densities.														
2	If grain density is available, porosity from dry and grain densities is used. If not, porosity from sat. and dry bulk densities is used.														
3															
4	All values in Columns E, G, H, and I have been checked against original sources by Nancy Brodsky. The sources are:														
5		DTN SNL01A05059301.005 for columns E and G													
6		DTN SNL03042594001.002 and SNL03042594001.003 for columns H and I													
7															
8					Dry		Sat		Grain	Porosity	Porosity	Porosities		diffs in porositie	diffs as %
9					Bulk		Bulk		Density	1-(db/gd)	sb-db	to use			
10	Drillhole	T/M unit	Depth	ID	Density	ID	Density	ID	(g/cm3)						
11															
12	NRG4	PTn	431.3	B	1.09			E	2.358	0.538	-	0.5377439			
13	NRG4	PTn	450.6	B	1.12			H	2.376	0.529	-	0.5286195			
14	NRG4	PTn	470.0	B	1.26	A	1.7	D	2.449	0.486	0.440	0.4855043		0.046	4.55%
15	NRG4	TSw1	529.0	B	2.12		2.22	D	2.539	0.165	0.100	0.1650256		0.065	6.50%
16	NRG4	TSw1	545.0	G	1.97			D	2.587	0.239	-	0.2385002			
17	NRG4	TSw1	586.2	B	2.08	A	2.26	I	2.582	0.194	0.180	0.1944229		0.014	1.44%
18	NRG4	TSw1	590.5	B	2.09			D	2.570	0.187	-	0.1867704			
19	NRG4	TSw1	610.5	B	2.20			H	2.570	0.144	-	0.1439689			
20	NRG4	TSw1	619.9	B	2.23			E	2.568	0.132	-	0.1316199			
21	NRG4	TSw1	654.0	B	2.20	A	2.32	C	2.549	0.137	0.120	0.1369164		0.017	1.69%
22															
23	NRG5	TSw1	781.8	A	2.14		2.29	B	2.539	0.157	0.150	0.1571485		0.007	0.71%
24	NRG5	TSw1	791.6	A	1.92		2.29	B	2.546	0.246	0.370	0.2458759		-0.124	-12.41%
25	NRG5	TSw2	834.8	B	2.31	A	2.39	C	2.536	0.089	0.080	0.0891167		0.009	0.91%
26	NRG5	TSw2	843.5	A	2.31		2.39	B	2.532	0.088	0.080	0.0876777		0.008	0.77%
27	NRG5	TSw2	848.0	B	2.23		2.34	C	2.537	0.121	0.110	0.1210091		0.011	1.10%
28	NRG5	TSw2	853.8	A	2.31		2.35	C	2.531	0.087	0.040	0.0873173		0.047	4.73%
29	NRG5	TSw2	874.9	B	2.31		2.35	C	2.528	0.086	0.040	0.0862342		0.046	4.62%
30	NRG5	TSw2	879.6	A	2.31		2.41	B	2.530	0.087	0.100	0.0869565		-0.013	-1.30%
31	NRG5	TSw2	886.5	B	2.22		2.35	C	2.533	0.124	0.130	0.1235689		-0.006	-0.64%
32	NRG5	TSw2	893.3	B	2.24		2.36	C	2.524	0.113	0.120	0.1125198		-0.007	-0.75%
33	NRG5	TSw2	899.8	B	2.24		2.35	C	2.517	0.110	0.110	0.1100516		0.000	0.01%
34															
35	NRG6	TCw	28.8	C	2.34	B	2.38			-	0.040	0.0400000			

Poros_tc / Sheet2 / Sheet3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
36	NRG6	TCw	98.1	I	2.31	H	2.37			-	0.060	0.0600000				
37	NRG6	TCw	111.0	I	2.25	H	2.34			-	0.090	0.0900000				
38	NRG6	PTn	152.9	E	1.34	D	1.77			-	0.430	0.4300000				
39	NRG6	PTn	187.0	F	1.05	E	1.54			-	0.490	0.4900000				
40	NRG6	PTn	241.5	E	0.91	D	1.52			-	0.610	0.6100000				
41	NRG6	TSw1	277.5	E	2.26	D	2.36			-	0.100	0.1000000				
42	NRG6	TSw1	321.1	E	2.18	D	2.33			-	0.150	0.1500000				
43	NRG6	TSw1	354.9	C	2.19	B	2.34			-	0.150	0.1500000				
44	NRG6	TSw1	392.1	D	2.20	C	2.24			-	0.040	0.0400000				
45	NRG6	TSw1	416.0	K	2.24	J	2.33			-	0.090	0.0900000				
46	NRG6	TSw1	421.8	D	2.22	C	2.3	E	2.546	0.127	0.077	0.1268657		0.050	4.99%	
47	NRG6	TSw1	425.3	B	2.18	A	2.31	C	2.529	0.138	0.130	0.1379992		0.008	0.80%	
48	NRG6	TSw1	451.2	B	2.05	A	2.22	C	2.516	0.185	0.170	0.1852146		0.015	1.52%	
49	NRG6	TSw1	556.1	B	1.81	A	2.26	C	2.505	0.277	0.450	0.2774451		-0.173	-17.26%	
50	NRG6	TSw1	693.1	C	2.18	C	2.31	D	2.524	0.136	0.130	0.1362916		0.006	0.63%	
51	NRG6	TSw2	757.0	B	2.28	A	2.38	E	2.522	0.096	0.100	0.0959556		-0.004	-0.40%	
52	NRG6	TSw2	778.1	B	2.29	A	2.3	E	2.500	0.084	0.010	0.0840000		0.074	7.40%	
53	NRG6	TSw2	787.5	B	2.23	A	2.34	C	2.512	0.112	0.110	0.1122611		0.002	0.23%	
54	NRG6	TSw2	802.7	D	2.27	C	2.32	F	2.507	0.095	0.050	0.0945353		0.045	4.45%	
55	NRG6	TSw2	809.4	B	2.28	A	2.36	E	2.511	0.092	0.080	0.0919952		0.012	1.20%	
56	NRG6	TSw2	900.4	D	2.19	C	2.33	G	2.560	0.145	0.140	0.1445313		0.005	0.45%	
57	NRG6	TSw2	926.3	E	2.24	D	2.4	H	2.571	0.129	0.160	0.1287437		-0.031	-3.13%	
58	NRG6	TSw2	987.0	B	2.26	A	2.35	D	2.561	0.118	0.090	0.1175322		0.028	2.75%	
59																
60	NRG7	TCw	18.6	D	2.33	C	2.39	E	2.506	0.070	0.060	0.0702314		0.010	1.02%	
61	NRG7	TCw	27.0	B	2.33	A	2.39	C	2.494	0.066	0.060	0.0657578		0.006	0.58%	
62	NRG7	TCw	56.8	D	2.07	C	2.23	F	2.498	0.171	0.160	0.1713371		0.011	1.13%	
63	NRG7	PTn	75.0	D	1.72	C	1.98	E	2.466	0.303	0.260	0.3025142		0.043	4.25%	
64	NRG7	PTn	91.6	D	1.34	C	1.74	E	2.321	0.423	0.400	0.4226626		0.023	2.27%	
65	NRG7	PTn	104.1	C	1.00	B	1.49	D	2.406	0.584	0.490	0.5843724		0.094	9.44%	
66	NRG7	PTn	113.1	B	1.32	C	1.7	E	2.208	0.402	0.380	0.4021739		0.022	2.22%	
67	NRG7	PTn	248.5	D	1.17	C	1.65	E	2.317	0.495	0.480	0.4950367		0.015	1.50%	
68	NRG7	PTn	293.3			C	1.78	D	2.295	-	-	-				
69	NRG7	TSw1	312.8	D	2.30	C	2.39	D	2.573	0.106	0.090	0.1061018		0.016	1.61%	
70																

Poros_tc / Sheet2 / Sheet3

Sources: The text and spreadsheet parts of this memo are from the Records Information System under Brodsky 2003 [DIRS 164584].
Source data for the spreadsheet are from DTNs: SNL01A05059301.005 [DIRS 109002], SNL03042594001.002 [DIRS 109607], and SNL03042594001.003 [DIRS 109608].
The memo references SNL 1998 [DIRS 118788].

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APPENDIX B

PROGRAM SPLICE INPUT CONTROL DATA FOR NRG4, NRG5, NRG6, AND NRG7 BOREHOLES

Table B-1. Input DTN List

DTN	Renamed Program Input File
SNL01A05059301.007 [DIRS 108980]	*s98424_003.txt*
SNL01A05059301.005 [DIRS 109002]	*s96370_001.txt*

SPLICE (STN: 10906-1.0-00 [DIRS 162672]) input:

```
delta 1.3  ft
title      Input data for the Hsu inverse thermal conductivity model
title            Boreholes NRG4, NRG5, NRG6 and NRG7
title              March 13, 2003
colhead        Sample        Porosity    Dry     Wet       Por table/row   TC
table
colhead ------------------+---------+---------+---------+---------+----+----
-----+
porinputfile s98424_003.txt
porsample   out 1 18  in  sample
porosity out 21 29 in  porosity
portable   out 51 60    in  $inputfile
porrow     out 62 66    in   row
readpor

tcinputfile s96370_001.txt
tctemp     out 0  0   in  temperature
tcond      out 0  0   in  'thermal '
drythermalcond out 30 38  in 'thermal '
!  for experiment = 'oven dry'
wetthermalcond out 39 47  in 'thermal '
!  for experiment = 'vacuum sat'
tctest       out  0  0   in  test
tcsample   out  0  0   in sample
tctable    out  67 76  in  $inputfile
readtc

outputfile nrghsuinv.inp
```

Source: STN 10906-1.0-00 [DIRS 162672].

NOTES: The colhead command lines exceed the width of this page and do not wrap in the original data file.
"Por" is an abbreviation for "porosity."
"TC" is an abbreviation for "thermal conductivity.'
The "delta 1.3 ft" line allows a difference of 1.3 feet in the porosity and thermal conductivity sample depths.
This appendix is a copy of data file *Inputs\HsuInv\nrgsplice.inp*, dated 3/13/03, 1:10PM, 938 bytes.

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APPENDIX C

REFORMAT INPUT CONTROL FILE FOR POROSITY DATA

Table C-1. Input DTN List

DTN	Renamed Program Input File
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_001.txt*

REFORMAT (STN 10907-2.0-00 [DIRS 162673]) input:

```
inputfile s01144_001.txt
outputfile r01144_001.txt

colhead ****************************************
colhead row#    sample number      porosity
colhead ****************************************
colhead

field out  1  4  in row
field out  9 13  in location
replace 'USW SD-7'  ' SD7-'
replace 'USW SD-9'  ' SD9-'
replace 'USW SD-12' 'SD12-'
keep  ' SD'   'SD'

!field "sample" contains depth in feet
field out 14 20  in sample
bounds 1400 1900
field out 28 33  in porosity
```

Sources: STN 10907-2.0-00 [DIRS 162673],
DTN MO0109HYMXPROP.001 [DIRS 155989].

NOTE: This appendix is a copy of data file *Inputs\HsuInv\ref_01144_001.inp*, dated 2/14/03 4:02PM, 493 bytes.

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APPENDIX D

REFORMAT INPUT CONTROL FILE FOR THERMAL CONDUCTIVITY DATA

Table D-1. Input DTN List

DTN	Renamed Program Input File
SNL22100196001.006 [DIRS 158213]	*s98169_002.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
inputfile   s98169_002.txt
outputfile  r98169_002.txt

colhead *************************************************
colhead row#      sample          test condition    temperature  thermal cond
colhead *************************************************
colhead
field  out  1  4   in row
field  out 12 26   in sample
field  out 28 49   in saturation
replace '0/'  'oven dry          110.'
replace '1/'  'oven dry          110.'
replace '2/'  'oven dry          110.'
replace '97/' 'vacuum saturated  70.'
replace '98/' 'vacuum saturated  70.'
replace '99/' 'vacuum saturated  70.'
keep  oven  vacuum
field  out 59 64  in  thermal
```

Source: STN 10907-2.0-00 [DIRS 162672].

NOTES: 1. The second colhead command line exceeds the width of this page and does not wrap in the original data file.

2. This appendix is a copy of data file *Inputs\HsuInv\ref_98169_002.inp*, dated 2/14/03 3:13AM, 655 bytes.

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APPENDIX E

PROGRAM SPLICE INPUT CONTROL DATA FOR SD7, SD9, AND SD12 BOREHOLES

Table E-1. Input DTN List

DTN	Renamed Program Input File
MO0109HYMXPROP.001 [DIRS 155989]	*r01144_001.txt*
SNL22100196001.006 [DIRS 158213]	*r98169_002.txt*

SPLICE (STN: 10906-1.0-00 [DIRS 162672]) input:

```
delta 1.3  ft

title      Input data for the Hsu inverse thermal conductivity model
title            Boreholes SD7, SD9, SD12
title              March 13, 2003
colhead        Sample        Porosity    Dry     Wet       Por table/row   TC
table
colhead ------------------+---------+--------+---------+---------+----+----
-----+
porinputfile r01144_001.txt
porsample   out 1 18  in  sample
porosity out 21 29 in  porosity
portable   out 51 60    in  $inputfile
porrow     out 62 66    in   row
readpor

tcinputfile r98169_002.txt
tctemp     out 0  0   in  temperature
tcond      out 0  0   in  'thermal '
drythermalcond out 30 38  in 'thermal '
!  for experiment = 'oven dry'
wetthermalcond out 39 47  in 'thermal '
!  for experiment = 'vacuum sat'
tctest       out  0  0   in  test
tcsample   out  0  0   in sample
tctable    out  67 76  in  $inputfile
readtc

outputfile sdhsuinv.inp
```

Sources: STN 10907-2.00 [DIRS 162673], DTN SNL22100196001.006 ([DIRS 158213] s98169_002).

NOTES:

1. The colhead command lines exceed the width of this page and do not wrap in the original data file.
2. “Por” is an abbreviation for “porosity.”
3. “TC” is an abbreviation for “thermal conductivity.”
4. This appendix is a copy of data file *Inputs\HsuInv\sdsplice.inp*, dated 3/13/03, 1:19PM, 926 bytes.

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APPENDIX F

REFORMAT INPUT CONTROL FILE TO APPEND LITHOSTRATIGRAPHY TO HSUINV OUTPUT

Table F-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*lithostratigraphy.txt*
SNF40060298001.001 [DIRS 107372]	*lithostratigraphy.txt*
SNL01A05059301.007 [DIRS 108980]	*nrghsuinvout.txt*
SNL01A05059301.005 [DIRS 109002]	*nrghsuinvout.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*sdhsuinvout.txt*
SNL22100196001.006 [DIRS 158213]	*sdhsuinvout.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
lsfile  ..\lithostratigraphy.txt
outputfile lhsuinv.out

start template 1
colhead *************************************************
colhead phi        ks         gc         sample            lithostratigraphy
colhead *************************************************
colhead

!copy porosity
field  out  1 10  in phi

!copy solid thermal conductivity
field  out 12 20  in ks

!copy gamma_c
field  out 23 32  in gc

!copy sample
field  out 34 49  in 34 49

!determine lithostratigrapy from sample number:
lithostrat  52 58  samplenum  34 49
end template 1
inputfile nrghsuinvout.txt
run template 1

start template 2

!copy porosity
field  out  1 10  in phi

!copy solid thermal conductivity
field  out 12 20  in ks

!copy gamma_c
field  out 23 32  in gc

!copy sample
field  out 34 49  in 34 49

!determine lithostratigrapy from sample number:
```

```
lithostrat  52 58  samplenum  34 49
end template 2
inputfile sdhsuinvout.txt
run template 2
```

Sources: STN 10907-2.0-00 [DIRS 162673],
STN 10804-1.0-00 [DIRS 158228].

NOTES:
1. The colhead lines exceed the width of this page and do not wrap in the original data file.
2. This appendix is a copy of data file *Inputs\HsuInv\ref_hsu_litho.inp*, dated 2/17/03, 4:49PM, 984 bytes.
3. Renamed program input files correspond to input files listed for Table 4-2

APPENDIX G

REFORMAT INPUT CONTROL FILE FOR HSUINV OUTPUT SEPARATION BY PARAMETER AND LAYER GROUPS

Table G-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	lhsuinv.out
SNF40060298001.001 [DIRS 107372]	lhsuinv.out
SNL01A05059301.007 [DIRS 108980]	lhsuinv.out
SNL01A05059301.005 [DIRS 109002]	lhsuinv.out
MO0109HYMXPROP.001 [DIRS 155989]	lhsuinv.out
SNL22100196001.006 [DIRS 158213]	lhsuinv.out

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
inputfile  lhsuinv.out

start template 1
title Welded layers
title 1
title Solid thermal conductivity
field  out 1 10  in ks
field  out 11 16 in lithos
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf
KEEP    Tcpm  Tcbm  Tctm  RHH
!append sample number:
field  out 20 35 in 34 49
end template 1
outputfile weldedks.dat
run template 1

start template 2
title Welded layers
title 1
title Gamma_c
field  out 1 10  in gc
field  out 11 16 in lithos
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf
KEEP    Tcpm  Tcbm  Tctm  RHH
!append sample number:
field  out 20 35 in 34 49
end template 2
outputfile weldedgc.dat
run template 2

start template 3
title Non-welded layers
title 1
title Solid thermal conductivity
field  out 1 10  in ks
field  out 11 16 in lithos
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2  Tptpv2
!append sample number:
field  out 20 35 in 34 49
end template 3
outputfile nonweldedks.dat
```

```
run template 3

start template 4
title Non-welded layers
title 1
title Gamma_c
field  out 1 10  in gc
field  out 11 16 in lithos
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2  Tptpv2
!append sample number:
field  out 20 35 in 34 49
end template 4
outputfile nonweldedgc.dat
run template 4

start template 5
title Vitric layers
title 1
title Solid thermal conductivity
field  out 1 10  in ks
field  out 11 16 in lithos
KEEP    Tpcpv3  Tptrv1  Tptpv3
!append sample number:
field  out 20 35 in 34 49
end template 5
outputfile vitricks.dat
run template 5

start template 6
title Vitric layers
title 1
title Gamma_c
field  out 1 10  in gc
field  out 11 16 in lithos
KEEP    Tpcpv3  Tptrv1  Tptpv3
!append sample number:
field  out 20 35 in 34 49
end template 6
outputfile vitricgc.dat
run template 6

start template 7
title Calico Hills layers
title 1
title Solid thermal conductivity
field  out 1 10  in ks
field  out 11 16 in lithos
KEEP    Tac   V-Z
!append sample number:
field  out 20 35 in 34 49
end template 7
outputfile calicoks.dat
run template 7

start template 8
title Calico Hills layers
```

```
title 1
title Gamma_c
field  out 1 10  in gc
field  out 11 16 in lithos
KEEP    Tac   V-Z
!append sample number:
field  out 20 35 in 34 49
end template 8
outputfile calicogc.dat
run template 8
```

Source: STN 10907-2.00 [DIRS 162673].

NOTES:

1. This appendix is a copy of data file *Inputs\HsuInv\ref_hsu_layers.inp*, dated 3/13/03, 2:25PM, 2473 bytes.
2. Renamed program input files correspond to input files listed for Table 4-2

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APPENDIX H

APPROXIMATIONS TO EXPONENTIAL DISTRIBUTION GROWTH AND DECAY RATES

The probability density for the exponential probability distribution (Bulmer 1979 [DIRS 111961], p. 97) is given by

$$f(x) = c\, e^{\lambda x}$$

When this distribution is used to approximate the γ_c and ϕ_m distributions, x is in the interval [0, 1]. The constant c is found by normalizing the integral of f(x) on the interval [0, 1]:

$$\int_0^1 f(x)dx = \left[\frac{c}{\lambda} e^{\lambda x}\right]_0^1 = 1$$

so

$$\frac{c}{\lambda}\left(e^{\lambda} - 1\right) = 1$$

Then

$$c = \frac{\lambda}{\left(e^{\lambda} - 1\right)}$$

The mean μ is given by

$$\mu = \int_0^1 x\; f(x)\, dx = c\int_0^1 x\, e^{\lambda x}\; dx = c\left[\left(\frac{x}{\lambda} - \frac{1}{\lambda^2}\right)e^{\lambda x}\right]_0^1$$

Then

$$\mu = \frac{\left(1 - 1/\lambda\right)e^{\lambda} + 1/\lambda}{\left(e^{\lambda} - 1\right)} \qquad \text{(Eq. H-1)}$$

When the exponential distribution is used as an approximation to γ_c, λ is positive and μ is usually greater than 0.7. To achieve this mean on the interval [0, 1], the exponential distribution must increase sharply near *x*=1. This means that λ is a relatively large positive number. Dividing the numerator and denominator of Equation H-1 by e^{λ}:

$$\mu = \frac{\left(1 - 1/\lambda\right) + e^{-\lambda}/\lambda}{1 - e^{-\lambda}}$$

Approximating $e^{-\lambda}$ as zero,

$$\mu = \left(1 - \frac{1}{\lambda}\right)$$

so

$$\lambda = \frac{1}{(1-\mu)} \qquad \text{(Eq. H-2)}$$

For non-welded gamma_c, μ = 0.9046. Using Equation H-2 with this mean, λ = 10.482. A more precise value of λ can be found by using Equation H-1 to make a table of values of μ for values of λ at and around λ = 10.482:

λ	μ
10.478	0.90459
10.480	0.90461
10.482	0.90463
10.484	0.90464

It is apparent from this table that when μ = 0.9046 the appropriate value of λ is 10.479.

When the exponential distribution is used as an approximation to the vitric porosity data, μ is 0.036. To achieve this small a mean on the interval [0, 1], the exponential distribution must decrease sharply near *x*=1. This means that λ is a relatively large negative number. In this case, e^{λ} can be approximated as 0, and Equation H-1 becomes:

$$\mu = -\frac{1}{\lambda}$$

so

$$\lambda = -\frac{1}{\mu} \qquad \text{(Eq. H-3)}$$

For vitric porosity, μ = 0.036. Using Equation H-3 with this mean, λ = −27.778, a more precise value of λ can be found by using Equation H-1 to make a table of values of μ for values of λ at and around λ = −27.778.

λ	μ
−27.776	0.03600
−27.778	0.03600
−27.780	0.03600

It is apparent from this table that μ is not very sensitive to small changes in λ, so the initial approximation λ = −27.778 is adequate to 5 significant digits.

APPENDIX I

REFORMAT INPUT CONTROL FILE TO EXTRACT MATRIX POROSITY FOR MODEL FROM SITE AND ENGINEERING PROPERTIES TABLES

Table I-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*lithostratigraphy.txt*
SNF40060298001.001 [DIRS 107372]	*lithostratigraphy.txt*
SNL01A05059301.007 [DIRS 108980]	*s98424_003.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_001.txt*
GS000508312231.006 [DIRS 153237]	*s00415_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_005.txt*
SNL02030193001.022 [DIRS 109613]	*s99111_001.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
lsfile  ..\lithostratigraphy.txt
outputfile mporosity.txt

start template 1

title QUALIFIED POROSITY DATA FOR MODEL CONSTRUCTION

colhead ******************************************
colhead porosity  litho-    location                 datasource    row#
colhead           strati-   (borehole id
colhead           graphy    + depth (ft))
colhead ******************************************
colhead

!porosity
field  out  1 8    in  porosity
numeric

!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum  sample

! location
field  out 21 40   in  sample

!datasource
field  out 46 55   in $inputfile

!row number
field  out 60 63   in row

end template 1

inputfile s98424_003.txt
run template 1


start template 2

!porosity
```

```
field  out  1 8    in  porosity
numeric

!determine lithostratigrapy from borehole id and depth:
lithostrat 11 18  bid location       depth   sample

! well id
field  out 21 33   in  location
keep "USW SD-7"  "USW SD-9"  "USW SD-12"
keep "USW NRG-6"  "USW NRG-7"

! depth in ft
field  out 35 40   in  sample

!datasource
field  out 46 55   in $inputfile

!row number
field  out 60 63   in  row

end template 2

inputfile  s01144_001.txt
run template 2


start template 3

!porosity
field  out  1 8    in  porosity
numeric

!determine lithostratigrapy from borehole id and depth:
lithostrat 11 18  bid location       depth   depth

! well id
field  out 21 30   in  location

! depth in ft
field  out 32 40   in  depth

!datasource
field  out 46 55   in $inputfile

!row number
field  out 60 63   in  row

!test description
field  out  68 74  in  experiment
keep  RH

end template 3

inputfile  s00415_001.txt
run template 3
```

```
start template 4

!porosity
field  out  1 8    in  porosity
scale 0.01
numeric

!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum  sample

! location
field  out 21 40   in  sample

!datasource
field  out 46 55   in $inputfile

!row number
field  out 60 63   in  row

end template 4

inputfile  s98484_001.txt
run template 4


start template 5

!porosity
field  out  1 8    in  porosity
scale 0.01
numeric

!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum  sample

! location
field  out 21 40   in  sample

!datasource
field  out 46 55   in $inputfile

!row number
field  out 60 63   in  row

end template 5

inputfile  s98484_005.txt
run template 5


start template 6

!porosity
field  out  1 8    in  porosity
scale 0.01
numeric
```

```
!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum  sample

! location
field  out 21 40   in  sample

!datasource
field  out 46 55   in $inputfile

!row number
field  out 60 63   in  row

end template 6

inputfile  s99111_001.txt
run template 6
```

Sources: STN 10907-2.0-00 [DIRS 162673], DTN GS000508312231.006 [DIRS 153237] S00415_001, DTN MO0109HYMXPROP.001 [DIRS 155989] s01144_001 (file *DATAQ.zip*), DTN SNL01A05059301.007 [DIRS 108980] s98424_003, DTN SNL02030193001.002 [DIRS 120575] S98484_001 and S98484_005, and DTN SNL02030193001.022 [DIRS 109613] S99111_001.

NOTE: This appendix is a copy of data file *Inputs\QVPorosity\mporosity.inp*, dated 3/12/03, 5:51PM, 3024 bytes.

APPENDIX J

REFORMAT INPUT CONTROL FILE TO SEPARATE MODEL MATRIX POROSITY BY GEOLOGIC UNIT

Table J-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*mporosity.txt*
SNF40060298001.001 [DIRS 107372]	*mporosity.txt*
SNL01A05059301.007 [DIRS 108980]	*mporosity.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*mporosity.txt*
GS000508312231.006 [DIRS 153237]	*mporosity.txt*
SNL02030193001.002 [DIRS 120575]	*mporosity.txt*
SNL02030193001.022 [DIRS 109613]	*mporosity.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
inputfile mporosity.txt

start template 1

title POROSITY DATA FOR NON-REPOSITORY WELDED LAYERS ABOVE CALICO HILLS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in litho
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf

! location
field  out 21 40   in  location

end template 1

OUTPUTFILE  mweldedpor.dat
run template 1



start template 2

title POROSITY DATA FOR NONWELDED LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
```

```
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2  Tptpv2

! location
field  out 21 40   in  location

end template 2

OUTPUTFILE  mnonweldedpor.dat
run template 2


start template 3

title POROSITY DATA FOR VITRIC LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in litho
KEEP    Tpcpv3  Tptrv1  Tptpv3

! location
field  out 21 40   in  location

end template 3

OUTPUTFILE  mvitricpor.dat
run template 3


start template 4

title POROSITY DATA FOR CALICO LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    Tac   Tacbt  V-Z

! location
field  out 21 40   in  location

end template 4

OUTPUTFILE  mcalicopor.dat
run template 4
```

```
start template 5

title POROSITY DATA FOR PROW PASS WELDED LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    Tcpm   Prowmd

! location
field  out 21 40   in  location

end template 5

OUTPUTFILE  mprowweldedpor.dat
run template 5


start template 6

title POROSITY DATA FOR PROW PASS NONWELDED LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    Tcplc  Tcplv  Tcpuc  Tcpuv  Tcpbt  Prowuv  Prowuc  Prowlc  Prowlv
KEEP    Prowbt  Tcp1  Tcp2  Tcp3  Tcp4  Tcpbt

! location
field  out 21 40   in  location

end template 6

OUTPUTFILE  mprownonweldedpor.dat
run template 6



start template 7

title POROSITY DATA FOR BULLFROG WELDED LAYERS

colhead 1
colhead porosity

!porosity
```

```
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    Tcbm  Tcb3  Tcb4  Bullfrogmd

! location
field  out 21 40   in  location

end template 7

OUTPUTFILE  mbullfrogweldedpor.dat
run template 7


start template 8

title POROSITY DATA FOR BULLFROG NONWELDED LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    Tcblv  Tcb1  Bullfroguv  Bullfroguc  Bullfroglc  Bullfroglv
Bullfrogbt
KEEP    Tcblc  Tcbuv  Tcbuc  Tcbbt

! location
field  out 21 40   in  location

end template 8

OUTPUTFILE  mbullfrognonweldedpor.dat
run template 8


start template 9

title POROSITY DATA FOR TRAM TUFF WELDED LAYERS

colhead 1
colhead porosity
```

```
!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    Tctm  Trammd

! location
field  out 21 40   in  location

end template 9

OUTPUTFILE  mtramweldedpor.dat
run template 9



start template 10

title POROSITY DATA FOR TRAM TUFF NONWELDED LAYERS

colhead 1
colhead porosity

!porosity
field  out 1 8   in  porosity

!lithostratigraphy
field  out 11 18     in  litho
KEEP    'Tct '  Tctuv  Tctuc  Tctlc  Tctlv  Tctbt  Tramuv  Tramuc  Tramlc
KEEP    Tramlv  Trambt

! location
field  out 21 40   in  location

end template 10

OUTPUTFILE  mtramnonweldedpor.dat
run template 10
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTES:

1. This appendix is a copy of data file *Inputs\QVPorosity\mlayers.inp*, dated 3/12/03, 6:07PM, 3905 bytes.
2. Renamed program input files correspond to input files listed for Table 4-3

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APPENDIX K

REFORMAT INPUT CONTROL FILE TO COMBINE DRY BULK DENSITY TABLES AND APPEND LITHOSTRATIGRAPHY

Table K-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*lithostratigraphy.txt*
SNF40060298001.001 [DIRS 107372]	*lithostratigraphy.txt*
GS000408312231.004 [DIRS 149582]	*s00276_001.txt*
GS000508312231.006 [DIRS 153237]	*s00415_001.txt*
GS950308312231.002 [DIRS 108990]	*s96015_001.txt*
GS950408312231.004 [DIRS 108986]	*s96021_001.txt*
GS940508312231.006 [DIRS 107149]	*s96024_003.txt*
GS930108312231.006 [DIRS 108997]	*s96025_001.txt*
GS920508312231.012 [DIRS 109001]	*s96026_001.txt*
GS940408312231.004 [DIRS 109000]	*s96027_001.txt*
GS951108312231.009 [DIRS 108984]	*s96037_001.txt*
GS951108312231.011 [DIRS 108992]	*s96049_001.txt*
GS960808312231.004 [DIRS 108985]	*s97058_001.txt*
GS980708312242.010 [DIRS 106752]	*s98248_004.txt*
GS980808312242.014 [DIRS 106748]	*s98285_001.txt*
GS951108312231.010 [DIRS 108983]	*s96046_001.txt*
GS920408312314.011 [DIRS 129660]	*s97135_002.txt*
GS930408312132.007 [DIRS 129625]	*s97276_001.txt*
SNL01A05059301.007 [DIRS 108980]	*s98424_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_002.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_004.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_005.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_001.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_003.txt*
SNL02030193001.008 [DIRS 120597]	*s98486_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_004.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_001.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_004.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_001.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_004.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_001.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_004.txt*
SNL02030193001.007 [DIRS 120582]	*s99106_001.txt*
SNL02030193001.014 [DIRS 109609]	*s99107_001.txt*
SNL02030193001.014 [DIRS 109609]	*s99107_004.txt*

Table K-1. Input DTN List (Continued)

DTN	Renamed Program Input File
SNL02030193001.015 [DIRS 120617]	*s99108_001.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_001.txt*
SNL02030193001.012 [DIRS 108416]	*s99110_001.txt*
SNL02030193001.022 [DIRS 109613]	*s99111_002.txt*
SNL02030193001.016 [DIRS 120619]	*s99112_001.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_001.txt*
SNL02030193001.018 [DIRS 109611]	*s99114_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_002.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_004.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_001.txt*
SNL01A05059301.002 [DIRS 150042]	*s99435_001.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
lsfile  ..\lithostratigraphy.txt
outputfile  dbd.txt

start template 1
title  Qualified, verified dry bulk density

colhead ********************************************************************
colhead dry       litho-   borehole       datasource   row    experiment
colhead bulk      strati-
colhead density   graphy
colhead (g/cc)
colhead ********************************************************************
colhead

!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 18  samplenum depth

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

!test type
```

```
field  out  56 62  in  experiment
keep  RH

end template 1

inputfile  s00276_001.txt
run template 1


start template 2
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  bid  location    depth  depth

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

!test type
field  out  56 62  in  experiment
keep  RH

end template 2

inputfile  s00415_001.txt
run template 2



start template 3
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  samplenum sample

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

!test type
field  out  56 62  in  experiment
keep  RH
```

```
end template 3

inputfile  s96015_001.txt
run template 3

inputfile  s96021_001.txt
run template 3

inputfile  s96024_003.txt
run template 3

inputfile  s96025_001.txt
run template 3

inputfile  s96026_001.txt
run template 3

inputfile  s96027_001.txt
run template 3

inputfile  s96037_001.txt
run template 3

inputfile  s96049_001.txt
run template 3

inputfile  s97058_001.txt
run template 3

inputfile  s98248_004.txt
run template 3

inputfile  s98285_001.txt
run template 3



start template 4
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  bid location    depthm depth

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

!test type
field  out  56 62  in  experiment
```

```
keep  RH

end template 4

inputfile  s96046_001.txt
run template 4



start template 5
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  bid location    depthm depth

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

end template 5

inputfile  s97135_002.txt
run template 5

inputfile  s97276_001.txt
run template 5



start template 6
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  samplenum  sample

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

end template 6

inputfile  s98424_001.txt
run template 6
```

```
inputfile  s98484_001.txt
run template 6

inputfile  s98484_002.txt
run template 6

inputfile  s98484_004.txt
run template 6

inputfile  s98484_005.txt
run template 6

inputfile  s98485_001.txt
run template 6

inputfile  s98485_003.txt
run template 6

inputfile  s98486_001.txt
run template 6

inputfile  s99100_001.txt
run template 6

inputfile  s99100_004.txt
run template 6

inputfile  s99101_001.txt
run template 6

inputfile  s99101_004.txt
run template 6

inputfile  s99104_001.txt
run template 6

inputfile  s99104_004.txt
run template 6

inputfile  s99105_001.txt
run template 6

inputfile  s99105_004.txt
run template 6

inputfile  s99106_001.txt
run template 6

inputfile  s99107_001.txt
run template 6

inputfile  s99107_004.txt
run template 6

inputfile  s99108_001.txt
run template 6
```

```
inputfile  s99109_001.txt
run template 6

inputfile  s99110_001.txt
run template 6

inputfile  s99111_002.txt
run template 6

inputfile  s99112_001.txt
run template 6

inputfile  s99113_001.txt
run template 6

inputfile  s99114_001.txt
run template 6

inputfile  s99115_001.txt
run template 6

inputfile  s99115_002.txt
run template 6



start template 7
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  bid location    depth  depth

!borehole
field  out  20 34  in location

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

end template 7

inputfile  s99116_001.txt
run template 7

inputfile  s99116_004.txt
run template 7

inputfile  s99117_001.txt
run template 7
```

```
start template 8
!dry bulk density
field  out  1 8  in dry
numeric

!lithostratigraphy
lithostrat  out  11 16  samplenum  sample

!borehole
field  out  20 24  in sample

!datasource
field  out  36 45  in  $inputfile

!row
field  out  49 53  in row#

end template 8

inputfile  s99435_001.txt
run template 8
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTE: This appendix is a copy of data file *Inputs\QVDryBulkDens\reformat_dbd.inp*, dated 3/12/03, 11:46AM, 5180 bytes.

APPENDIX L

REFORMAT INPUT CONTROL FILE FOR DRY BULK DATA SEPARATION BY LAYER GROUPS

Table L-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*dbd.txt*
SNF40060298001.001 [DIRS 107372]	*dbd.txt*
GS000408312231.004 [DIRS 149582]	*dbd.txt*
GS000508312231.006 [DIRS 153237]	*dbd.txt*
GS950308312231.002 [DIRS 108990]	*dbd.txt*
GS950408312231.004 [DIRS 108986]	*dbd.txt*
GS940508312231.006 [DIRS 107149]	*dbd.txt*
GS930108312231.006 [DIRS 108997]	*dbd.txt*
GS920508312231.012 [DIRS 109001]	*dbd.txt*
GS940408312231.004 [DIRS 109000]	*dbd.txt*
GS951108312231.009 [DIRS 108984]	*dbd.txt*
GS951108312231.011 [DIRS 108992]	*dbd.txt*
GS960808312231.004 [DIRS 108985]	*dbd.txt*
GS980708312242.010 [DIRS 106752]	*dbd.txt*
GS980808312242.014 [DIRS 106748]	*dbd.txt*
GS951108312231.010 [DIRS 108983]	*dbd.txt*
GS920408312314.011 [DIRS 129660]	*dbd.txt*
GS930408312132.007 [DIRS 129625]	*dbd.txt*
SNL01A05059301.007 [DIRS 108980]	*dbd.txt*
SNL02030193001.002 [DIRS 120575]	*dbd.txt*
SNL02030193001.002 [DIRS 120575]	*dbd.txt*
SNL02030193001.002 [DIRS 120575]	*dbd.txt*
SNL02030193001.002 [DIRS 120575]	*dbd.txt*
SNL02030193001.004 [DIRS 108415]	*dbd.txt*
SNL02030193001.004 [DIRS 108415]	*dbd.txt*
SNL02030193001.008 [DIRS 120597]	*dbd.txt*
SNL02030193001.003 [DIRS 120578]	*dbd.txt*
SNL02030193001.003 [DIRS 120578]	*dbd.txt*
SNL02030193001.006 [DIRS 120579]	*dbd.txt*
SNL02030193001.006 [DIRS 120579]	*dbd.txt*
SNL02030193001.013 [DIRS 120614]	*dbd.txt*
SNL02030193001.013 [DIRS 120614]	*dbd.txt*
SNL02030193001.005 [DIRS 122545]	*dbd.txt*
SNL02030193001.005 [DIRS 122545]	*dbd.txt*
SNL02030193001.007 [DIRS 120582]	*dbd.txt*
SNL02030193001.014 [DIRS 109609]	*dbd.txt*
SNL02030193001.014 [DIRS 109609]	*dbd.txt*

Table L-1. Input DTN List (Continued)

DTN	Renamed Program Input File
SNL02030193001.015 [DIRS 120617]	*dbd.txt*
SNL02030193001.009 [DIRS 109614]	*dbd.txt*
SNL02030193001.012 [DIRS 108416]	*dbd.txt*
SNL02030193001.022 [DIRS 109613]	*dbd.txt*
SNL02030193001.016 [DIRS 120619]	*dbd.txt*
SNL02030193001.017 [DIRS 109610]	*dbd.txt*
SNL02030193001.018 [DIRS 109611]	*dbd.txt*
SNL02030193001.019 [DIRS 108431]	*dbd.txt*
SNL02030193001.019 [DIRS 108431]	*dbd.txt*
SNL02030193001.020 [DIRS 108432]	*dbd.txt*
SNL02030193001.020 [DIRS 108432]	*dbd.txt*
SNL02030193001.021 [DIRS 108433]	*dbd.txt*
SNL01A05059301.002 [DIRS 150042]	*dbd.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
!  This Reformat input control file generates dry bulk density files by
!  geologic layer group (welded, non-welded, ...) that are suitable as
!  input files for program histplt  (histogram plotter).

inputfile dbd.txt

start template 1
title DRY BULK DENSITY DATA FOR NON-REPOSITORY WELDED LAYERS ABOVE CALICO
HILLS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 1

OUTPUTFILE  weldeddbd.dat
run template 1



start template 2
title DRY BULK DENSITY DATA FOR NONWELDED LAYERS
colhead 1
```

```
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2  Tptpv2
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 2

OUTPUTFILE  nonweldeddbd.dat
run template 2



start template 3
title DRY BULK DENSITY DATA FOR VITRIC LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tpcpv3  Tptrv1  Tptpv3
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 3

OUTPUTFILE  vitricdbd.dat
run template 3



start template 4
title DRY BULK DENSITY DATA FOR CALICO LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tac   Tacbt  V-Z
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
```

```
end template 4

OUTPUTFILE  calicodbd.dat
run template 4


start template 5
title DRY BULK DENSITY DATA FOR PROW PASS WELDED LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tcpm   Prowmd
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 5

OUTPUTFILE  prowweldeddbd.dat
run template 5



start template 6
title DRY BULK DENSITY DATA FOR PROW PASS NONWELDED LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tcplc  Tcplv  Tcpuc  Tcpuv  Tcpbt  Prowuv  Prowuc  Prowlc  Prowlv
KEEP    Prowbt   Tcpbt
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 6

OUTPUTFILE  prownonweldeddbd.dat
run template 6


start template 7
title DRY BULK DENSITY DATA FOR BULLFROG WELDED LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
```

```
field  out 11 18     in litho
KEEP    Tcbm  Bullfrogmd
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 7

OUTPUTFILE  bullfrogweldeddbd.dat
run template 7



start template 8
title DRY BULK DENSITY DATA FOR BULLFROG NONWELDED LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tcblv  Bullfroguv  Bullfroguc  Bullfroglc  Bullfroglv  Bullfrogbt
KEEP    Tcblc  Tcbuv  Tcbuc  Tcbbt
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 8

OUTPUTFILE  bullfrognonweldeddbd.dat
run template 8



start template 9
title DRY BULK DENSITY DATA FOR TRAM TUFF WELDED LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    Tctm  Trammd
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 9

OUTPUTFILE  tramweldeddbd.dat
run template 9
```

```
start template 10
title DRY BULK DENSITY DATA FOR TRAM TUFF NONWELDED LAYERS
colhead 1
colhead dry bulk density
! dry bulk density
field  out 1 8   in dry
!lithostratigraphy
field  out 11 18     in litho
KEEP    'Tct '  Tctuv  Tctuc  Tctlc  Tctlv  Tctbt  Tramuv  Tramuc  Tramlc
KEEP    Tramlv  Trambt
! location
field  out 21 40   in  borehole
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 10

OUTPUTFILE  tramnonweldeddbd.dat
run template 10
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTES:

1. This appendix is a copy of data file *Inputs\QVDryBulkDens\dbdlayers.inp*, dated 3/28/03, 3:44 PM, 5063 bytes.
3. Renamed program input files correspond to input files listed for Table 4-5

APPENDIX M

REFORMAT INPUT CONTROL FILE TO COMBINE POROSITY TABLES AND APPEND LITHOSTRATIGRAPHY FOR MODEL VALIDATION

Table M-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*lithostratigraphy.txt*
SNF40060298001.001 [DIRS 107372]	*lithostratigraphy.txt*
GS000408312231.004 [DIRS 149582]	*s00276_001.txt*
MO0012POROCHOL.000 [DIRS 153376]	*s00452_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_004.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_006.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_001.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_005.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_001.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_032.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_033.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_034.txt*
GS950308312231.002 [DIRS 108990]	*s96015_001.txt*
GS950308312231.002 [DIRS 108990]	*s96015_002.txt*
GS950408312231.004 [DIRS 108986]	*s96021_002.txt*
GS940508312231.006 [DIRS 107149]	*s96024_002.txt*
GS930108312231.006 [DIRS 108997]	*s96025_002.txt*
GS920508312231.012 [DIRS 109001]	*s96026_002.txt*
GS940408312231.004 [DIRS 109000]	*s96027_002.txt*
GS951108312231.009 [DIRS 108984]	*s96037_002.txt*
GS951108312231.011 [DIRS 108992]	*s96049_001.txt*
GS960808312231.004 [DIRS 108985]	*s97058_002.txt*
GS920408312314.011 [DIRS 129660]	*s97135_007.txt*
GS930408312132.007 [DIRS 129625]	*s97276_003.txt*
GS980708312242.010 [DIRS 106752]	*s98248_006.txt*
GS980808312242.014 [DIRS 106748]	*s98285_002.txt*
GS951108312231.010 [DIRS 108983]	*s96046_001.txt*
SNL02030193001.001 [DIRS 120572]	*s98483_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_002.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_004.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_001.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_003.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_005.txt*
SNL02030193001.008 [DIRS 120597]	*s98486_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_004.txt*

Table M-1. Input DTN List (Continued)

DTN	Renamed Program Input File
SNL02030193001.006 [DIRS 120579]	*s99101_001.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_004.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_001.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_004.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_005.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_001.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_004.txt*
SNL02030193001.007 [DIRS 120582]	*s99106_001.txt*
SNL02030193001.015 [DIRS 120617]	*s99108_001.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_001.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_002.txt*
SNL02030193001.012 [DIRS 108416]	*s99110_001.txt*
SNL02030193001.022 [DIRS 109613]	*s99111_002.txt*
SNL02030193001.016 [DIRS 120619]	*s99112_001.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_001.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_003.txt*
SNL02030193001.018 [DIRS 109611]	*s99114_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_002.txt*
SNL02030193001.028 [DIRS 159972]	*s99121_001.txt*
SNL01A05059301.002 [DIRS 150042]	*s99435_001.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
lsfile  ../../lithostratigraphy.txt
outputfile vporosity.txt

start template 1
title QUALIFIED POROSITY DATA FOR MODEL VALIDATION
colhead ******************************************
colhead porosity  litho-    location             datasource     row#
colhead           strati-   (borehole id
colhead           graphy    + depth (ft))
colhead ******************************************
colhead
!porosity
field  out  1 8    in  porosity
numeric
!determine lithostratigrapy from sample number (in the depth field):
lithostrat 11 18  samplenum  depth
! location is in the depth field:
field  out 21 40   in  depth
!datasource
```

```
field  out 42 51   in $inputfile
!row number
field  out 57 60   in row
end template 1

inputfile s00276_001.txt
run template 1



start template 2
!porosity
field  out  1 8    in  porosity
numeric
!determine lithostratigrapy from borehole id and depth:
lithostrat 11 18  bid location       depth   depth
! well id
field  out 21 31   in  location
! depth in ft
field  out 33 40   in  depth
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in  row
end template 2

!inputfile s00415_001.txt
!run template 2



start template 3
!porosity (in %)
field  out  1 8    in  porosity
numeric
scale 0.01
!determine lithostratigrapy from borehole id and depth:
lithostrat 11 18  bid location       depth   depth
! well id
field  out 21 31   in  location
! depth in ft
field  out 33 40   in  depth
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in  row
end template 3

inputfile s00452_001.txt
run template 3
inputfile s99116_001.txt
run template 3
inputfile s99116_004.txt
run template 3
inputfile s99116_006.txt
run template 3
inputfile s99117_001.txt
```

```
run template 3
inputfile s99117_005.txt
run template 3



start template 4
!porosity
field  out  1 8    in  porosity
numeric
!determine lithostratigrapy from borehole id and depth:
lithostrat 11 18  bid location       depth   sample
! well id
field  out 21 32   in  location
replace "USW NRG-7"  "USW NRG-7"
keep   "UE-25 UZ #16"  "USW NRG-6"  "USW NRG-7"   "USW SD-12"   "USW UZ-14"
keep   "USW UZ-7a"   "USW UZ-N11"   "USW UZ-N15"   "USW UZ-N16"   "USW UZ-N17"
keep   "USW UZ-N27"   "USW UZ-N31"   "USW UZ-N32"   "USW UZ-N33"   "USW UZ-
N34"
keep   "USW UZ-N35"   "USW UZ-N36"   "USW UZ-N37"   "USW UZ-N38"   "USW UZ-
N53"
keep   "USW UZ-N54"   "USW UZ-N55"   "USW UZ-N57"   "USW UZ-N58"   "USW UZ-
N59"
keep   "USW UZ-N61"   "USW UZ-N62"   "USW UZ-N63"   "USW UZ-N64"

! depth in ft is in the sample designation field
field  out 34 40   in  sample
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in  row
end template 4

inputfile s01144_001.txt
run template 4



start template 5
!porosity
field  out  1 8    in  porosity
numeric
!determine lithostratigrapy from borehole id and depth:
lithostrat 11 18  bid sample       depth  depth
! well id is in the sample designation field
field  out 21 28   in  sample
! depth in ft
field  out 30 40   in  depth
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in  row
end template 5

inputfile s01144_032.txt
run template 5
inputfile s01144_033.txt
```

```
run template 5
inputfile s01144_034.txt
run template 5



start template 6
!porosity
field  out  1 8    in  porosity
numeric
!determine lithostratigrapy from sample number
lithostrat 11 18  samplenum  sample
! location is in the depth field:
field  out 21 40   in  sample
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in row
end template 6

inputfile s96015_001.txt
run template 6
inputfile s96015_002.txt
run template 6
inputfile s96021_002.txt
run template 6
inputfile s96024_002.txt
run template 6
inputfile s96025_002.txt
run template 6
inputfile s96026_002.txt
run template 6
inputfile s96027_002.txt
run template 6
inputfile s96037_002.txt
run template 6
inputfile s96049_001.txt
run template 6
inputfile s97058_002.txt
run template 6
inputfile s98248_006.txt
run template 6
inputfile s98285_002.txt
run template 6
!! inputfile s98424_003.txt was used to build the model



start template 7
!porosity
field  out  1 8    in  porosity
numeric
!determine lithostratigrapy from location + depth
lithostrat 11 18  bid location     depthm  depth
! location is in the depth field:
field  out 21 29   in  location
field  out 31 40   in  depth
```

```
scale 3.2808
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in row
end template 7

inputfile s96046_001.txt
run template 7



start template 8
!porosity in %
field  out  1 8    in  porosity
numeric
scale 0.01
!determine lithostratigrapy from sample number
lithostrat 11 18  samplenum  sample
! location
field  out 21 40   in  sample
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in row
end template 8

inputfile s98483_001.txt
run template 8
!inputfile s98484_001.txt
!run template 8
inputfile s98484_002.txt
run template 8
inputfile s98484_004.txt
run template 8
!inputfile s98484_005.txt
!run template 8
inputfile s98485_001.txt
run template 8
inputfile s98485_003.txt
run template 8
inputfile s98485_005.txt
run template 8
inputfile s98486_001.txt
run template 8
inputfile s99100_001.txt
run template 8
inputfile s99100_004.txt
run template 8
inputfile s99101_001.txt
run template 8
inputfile s99101_004.txt
run template 8
inputfile s99104_001.txt
run template 8
inputfile s99104_004.txt
run template 8
```

```
inputfile s99104_005.txt
run template 8
inputfile s99105_001.txt
run template 8
inputfile s99105_004.txt
run template 8
inputfile s99106_001.txt
run template 8
inputfile s99108_001.txt
run template 8
inputfile s99109_001.txt
run template 8
inputfile s99109_002.txt
run template 8
inputfile s99110_001.txt
run template 8
!inputfile s99111_001.txt
!run template 8
inputfile s99111_002.txt
run template 8
inputfile s99112_001.txt
run template 8
inputfile s99113_001.txt
run template 8
inputfile s99113_003.txt
run template 8
inputfile s99114_001.txt
run template 8
inputfile s99115_001.txt
run template 8
inputfile s99115_002.txt
run template 8
inputfile s99121_001.txt
run template 8
inputfile s99435_001.txt
run template 8



start template 9
!porosity in %
field  out  1 8    in  porosity
numeric
scale 0.01
!determine lithostratigrapy from sample number
lithostrat 11 18  bid  location   depthm  depth
! location is in the depth field:
field  out 21 29   in  location
field  out 31 40   in  depth
scale 3.2808
!datasource
field  out 42 51   in $inputfile
!row number
field  out 57 60   in row
end template 9
```

```
inputfile s97135_007.txt
run template 9
inputfile r97276_003.txt
run template 9
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTE: This appendix is a copy of data file *Inputs\QVPorosity\vporosity.inp* dated 4/7/03, 12:11 PM, 7093 bytes.

APPENDIX N

REFORMAT INPUT CONTROL FILE TO SEPARATE POROSITY DATA BY GEOLOGIC LAYER

Table N-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*vporosity.txt*
SNF40060298001.001 [DIRS 107372]	*vporosity.txt*
GS000408312231.004 [DIRS 149582]	*vporosity.txt*
MO0012POROCHOL.000 [DIRS 153376]	*vporosity.txt*
SNL02030193001.020 [DIRS 108432]	*vporosity.txt*
SNL02030193001.020 [DIRS 108432]	*vporosity.txt*
SNL02030193001.020 [DIRS 108432]	*vporosity.txt*
SNL02030193001.021 [DIRS 108433]	*vporosity.txt*
SNL02030193001.021 [DIRS 108433]	*vporosity.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*vporosity.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*vporosity.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*vporosity.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*vporosity.txt*
GS950308312231.002 [DIRS 108990]	*vporosity.txt*
GS950308312231.002 [DIRS 108990]	*vporosity.txt*
GS950408312231.004 [DIRS 108986]	*vporosity.txt*
GS940508312231.006 [DIRS 107149]	*vporosity.txt*
GS930108312231.006 [DIRS 108997]	*vporosity.txt*
GS920508312231.012 [DIRS 109001]	*vporosity.txt*
GS940408312231.004 [DIRS 109000]	*vporosity.txt*
GS951108312231.009 [DIRS 108984]	*vporosity.txt*
GS951108312231.011 [DIRS 108992]	*vporosity.txt*
GS960808312231.004 [DIRS 108985]	*vporosity.txt*
GS920408312314.011 [DIRS 129660]	*vporosity.txt*
GS930408312132.007 [DIRS 129625]	*vporosity.txt*
GS980708312242.010 [DIRS 106752]	*vporosity.txt*
GS980808312242.014 [DIRS 106748]	*vporosity.txt*
GS951108312231.010 [DIRS 108983]	*vporosity.txt*
SNL02030193001.001 [DIRS 120572]	*vporosity.txt*
SNL02030193001.002 [DIRS 120575]	*vporosity.txt*
SNL02030193001.002 [DIRS 120575]	*vporosity.txt*
SNL02030193001.004 [DIRS 108415]	*vporosity.txt*
SNL02030193001.004 [DIRS 108415]	*vporosity.txt*
SNL02030193001.004 [DIRS 108415]	*vporosity.txt*
SNL02030193001.008 [DIRS 120597]	*vporosity.txt*
SNL02030193001.003 [DIRS 120578]	*vporosity.txt*
SNL02030193001.003 [DIRS 120578]	*vporosity.txt*
SNL02030193001.006 [DIRS 120579]	*vporosity.txt*

Table N-1. Input DTN List (Continued)

DTN	Renamed Program Input File
SNL02030193001.006 [DIRS 120579]	*vporosity.txt*
SNL02030193001.013 [DIRS 120614]	*vporosity.txt*
SNL02030193001.013 [DIRS 120614]	*vporosity.txt*
SNL02030193001.013 [DIRS 120614]	*vporosity.txt*
SNL02030193001.005 [DIRS 122545]	*vporosity.txt*
SNL02030193001.005 [DIRS 122545]	*vporosity.txt*
SNL02030193001.007 [DIRS 120582]	*vporosity.txt*
SNL02030193001.015 [DIRS 120617]	*vporosity.txt*
SNL02030193001.009 [DIRS 109614]	*vporosity.txt*
SNL02030193001.009 [DIRS 109614]	*vporosity.txt*
SNL02030193001.012 [DIRS 108416]	*vporosity.txt*
SNL02030193001.022 [DIRS 109613]	*vporosity.txt*
SNL02030193001.016 [DIRS 120619]	*vporosity.txt*
SNL02030193001.017 [DIRS 109610]	*vporosity.txt*
SNL02030193001.017 [DIRS 109610]	*vporosity.txt*
SNL02030193001.018 [DIRS 109611]	*vporosity.txt*
SNL02030193001.019 [DIRS 108431]	*vporosity.txt*
SNL02030193001.019 [DIRS 108431]	*vporosity.txt*
SNL02030193001.028 [DIRS 159972]	*vporosity.txt*
SNL01A05059301.002 [DIRS 150042]	*vporosity.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
!  This Reformat input control file generates porosity files by
!  geologic layer group (welded, non-welded, ...) that are suitable as
!  input files for program histplt  (histogram plotter).

inputfile vporosity.txt

start template 1
title VALIDATION POROSITY DATA FOR WELDED LAYERS ABOVE CALICO HILLS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 1
```

```
OUTPUTFILE  vweldedpor.dat
run template 1


start template 2
title VALIDATION POROSITY DATA FOR NONWELDED LAYERS ABOVE CALICO HILLS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2    Tptpv2
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 2

OUTPUTFILE  vnonweldedpor.dat
run template 2



start template 3
title VALIDATION POROSITY DATA FOR VITRIC LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tpcpv3  Tptrv1  Tptpv3
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 3

OUTPUTFILE  vvitricpor.dat
run template 3



start template 4
title VALIDATION POROSITY DATA FOR CALICO LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
```

```
KEEP    Tac   Tacbt  V-Z
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 4

OUTPUTFILE  vcalicopor.dat
run template 4


start template 5
title VALIDATION POROSITY DATA FOR PROW PASS WELDED LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcpm   Prowmd
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 5

OUTPUTFILE  vprowweldedpor.dat
run template 5



start template 6
title VALIDATION POROSITY DATA FOR PROW PASS NONWELDED LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcplc  Tcplv  Tcpuc  Tcpuv  Tcpbt  Prowuv  Prowuc  Prowlc  Prowlv
KEEP    Prowbt  Tcpbt   Tcp1  Tcp2  Tcp3  Tcp4
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 6

OUTPUTFILE  vprownonweldedpor.dat
run template 6
```

```
start template 7
title VALIDATION POROSITY DATA FOR BULLFROG WELDED LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcbm  Bullfrogmd   Tcb3   Tcb4
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 7

OUTPUTFILE  vbullfrogweldedpor.dat
run template 7



start template 8
title VALIDATION POROSITY DATA FOR BULLFROG NONWELDED LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcblv  Bullfroguv  Bullfroguc  Bullfroglc  Bullfroglv  Bullfrogbt
KEEP    Tcblc  Tcbuv  Tcbuc  Tcbbt  Tcb1  Tcb2
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 8

OUTPUTFILE  vbullfrognonweldedpor.dat
run template 8



start template 9
title VALIDATION POROSITY DATA FOR TRAM TUFF WELDED LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tctm  Trammd
! location
field  out 21 40   in  21 40
!data source
```

```
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 9

OUTPUTFILE  vtramweldedpor.dat
run template 9



start template 10
title VALIDATION POROSITY DATA FOR TRAM TUFF NONWELDED LAYERS
colhead 1
colhead validation porosity
! validation porosity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    'Tct '  Tctuv  Tctuc  Tctlc  Tctlv  Tctbt  Tramuv  Tramuc  Tramlc
KEEP    Tramlv  Trambt
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
end template 10

OUTPUTFILE  vtramnonweldedpor.dat
run template 10
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTES:

1. This appendix is a copy of data file *Inputs\QVPorosity\vporlayers.inp*, dated 3/28/03, 4:42PM, 5200 bytes.
2. Renamed program input files correspond to input files listed for Table 4-6

APPENDIX O

REFORMAT INPUT CONTROL FILE TO COMBINE VALIDATION THERMAL CONDUCTIVITY TABLES AND APPEND LITHOSTRATIGRAPHY

Table O-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*lithostratigraphy.txt*
SNF40060298001.001 [DIRS 107372]	*lithostratigraphy.txt*
SN0011T0571897.014 [DIRS 154449]	*s00441_001.txt*
SNL01A05059301.005 [DIRS 109002]	*s96370_001.txt*
SNL22100196001.006 [DIRS 158213]	*s98169_002.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
lsfile  ..\lithostratigraphy.txt
outputfile  vtc.txt

start template 1
title Validation Thermal Conductivity Data
colhead ******************************************
colhead TC DATA   litho-    location             datasource     row#  temp
type
colhead           strati-   (borehole id
colhead           graphy    + depth(ft))
colhead ******************************************
colhead
! thermal conductivity
field  out  1 8    in  "thermal cond"
rlist  out  63 72    separator /  rval "70.   wet"/"110.  dry"
!copy lithostratigrapy
field   out  11 18  in lithostratigrap
! sample id  -- none
field  out 21 40   in  sample
!datasource
field  out 42 51   in  $inputfile
!row number
field  out  57 60  in  row
end template 1

inputfile s00441_001.txt
run template 1



start template 2
! thermal conductivity
field  out  1 8    in  "thermal cond"
numeric
!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum sample
! location = sample number
field  out 21 40   in  sample
!datasource
field  out 42 51   in  $inputfile
!row number
field  out  57 60  in  row
```

```
! temperature
field  out  63 66  in temperature
bounds 65. 75.
! type (wet or dry):
field  out  69 72  in  test
replace  oven       dry
replace  air        dry
keep    dry
end template 2

inputfile s96370_001.txt
run template 2



start template 3
! thermal conductivity
field  out  1 8    in  "thermal cond"
numeric
!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum sample
! location = sample number
field  out 21 40   in  sample
!  these samples were not used to build the model:
keep   NRG-4-431.3-SNL-B  NRG-4-450.6-SNL-B  NRG-4-545.0-SNL-G
keep   NRG-4-590.5-SNL-B  NRG-4-610.5-SNL-B  NRG-4-619.9-SNL-B
keep   NRG-6-354.9-SNL    NRG-7-293.3-SNL-C
!datasource
field  out 42 51   in  $inputfile
!row number
field  out  57 60  in  row
! temperature
field  out  63 66  in temperature
bounds 105. 115.
! type (wet or dry):
field  out  69 72  in  test
replace  oven       dry
replace  air        dry
keep     dry
end template 3

inputfile s96370_001.txt
run template 3



start template 4
! thermal conductivity
field  out  1 8    in  "thermal cond"
numeric
!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum sample
! location = sample number
field  out 21 40   in  sample
keep   NRG-4-431.3-SNL-B  NRG-4-450.6-SNL-B  NRG-4-545.0-SNL-G
keep   NRG-4-590.5-SNL-B  NRG-4-610.5-SNL-B  NRG-4-619.9-SNL-B
keep   NRG-6-354.9-SNL    NRG-7-293.3-SNL-C
```

```
!datasource
field  out 42 51   in  $inputfile
!row number
field  out  57 60  in  row
! temperature
field  out  63 66  in temperature
bounds 65. 75.
! type (wet or dry):
field  out  69 72  in  test
replace  vacuum     wet
keep     wet
end template 4

inputfile s96370_001.txt
run template 4


start template 5
! thermal conductivity
field  out  1 8    in  "thermal cond"
numeric
!determine lithostratigrapy from sample number:
lithostrat 11 18  samplenum sample
! location = sample number
field  out 21 40   in  sample
! this sample was not used to build the model
keep   SD12-1442.8-A
!datasource
field  out 42 51   in  $inputfile
!row number
field  out  57 60  in  row
! type (wet or dry):
field  out  69 72  in  saturation
replace  98/     wet
replace  97/     wet
replace  0/      dry
replace  1/      dry
keep    wet  dry
end template 5

inputfile s98169_002.txt
run template 5
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTES: 1. The second colhead command line is wider than this page and does not wrap in the original file.
2. This appendix is a copy of data file *Inputs\QVTC\vtc.inp*, dated 3/28/03, 4:57PM, 3565 bytes.

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APPENDIX P

REFORMAT INPUT CONTROL FILE TO SEPARATE VALIDATION THERMAL CONDUCTIVITY DATA BY SATURATION AND GEOLOGIC LAYER

Table P-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*vtc.txt*
SNF40060298001.001 [DIRS 107372]	*vtc.txt*
SN0011T0571897.014 [DIRS 154449]	*vtc.txt*
SNL01A05059301.005 [DIRS 109002]	*vtc.txt*
SNL22100196001.006 [DIRS 158213]	*vtc.txt*

REFORMAT (STN: 10907-2.0-00 [DIRS 162673]) input:

```
!  This Reformat input control file generates wet and dry thermal conductivity
!  files by geologic layer group (welded, non-welded, ...) that are suitable
!  as input files for program histplt  (histogram plotter).

inputfile vtc.txt

start template 1
title DRY THERMAL CONDUCTIVITY DATA FOR WELDED LAYERS ABOVE CALICO HILLS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 1

OUTPUTFILE  vweldeddtc.dat
run template 1



start template 2
title DRY THERMAL CONDUCTIVITY DATA FOR NON-WELDED LAYERS ABOVE CALICO HILLS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2  Tptpv2
```

```
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 2

OUTPUTFILE  vnonweldeddtc.dat
run template 2



start template 3
title DRY THERMAL CONDUCTIVITY DATA FOR VITRIC LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tpcpv3  Tptrv1  Tptpv3
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 3

OUTPUTFILE  vvitricdtc.dat
run template 3



start template 4
title DRY THERMAL CONDUCTIVITY DATA FOR CALICO LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tac   Tacbt  V-Z
! location
field  out 21 40   in  21 40
!data source
```

```
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 4

OUTPUTFILE  vcalicodtc.dat
run template 4


start template 5
title DRY THERMAL CONDUCTIVITY DATA FOR PROW PASS WELDED LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcpm   Prowmd
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 5

OUTPUTFILE  vprowweldeddtc.dat
run template 5



start template 6
title DRY THERMAL CONDUCTIVITY DATA FOR PROW PASS NONWELDED LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcplc  Tcplv  Tcpuc  Tcpuv  Tcpbt  Prowuv  Prowuc  Prowlc  Prowlv
KEEP    Prowbt  Tcpbt Tcp1  Tcp2  Tcp3  Tcp4
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
```

```
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 6

OUTPUTFILE  vprownonweldeddtc.dat
run template 6


start template 7
title DRY THERMAL CONDUCTIVITY DATA FOR BULLFROG WELDED LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcbm   Bullfrogmd   Tcb3   Tcb4
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 7

OUTPUTFILE  vbullfrogweldeddtc.dat
run template 7



start template 8
title DRY THERMAL CONDUCTIVITY DATA FOR BULLFROG NONWELDED LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcblv  Bullfroguv  Bullfroguc  Bullfroglc  Bullfroglv  Bullfrogbt
KEEP    Tcblc  Tcbuv  Tcbuc  Tcbbt   Tcb1   Tcb2
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
```

```
field  out 69 72   in type
keep  dry
end template 8

OUTPUTFILE  vbullfrognonweldeddtc.dat
run template 8



start template 9
title DRY THERMAL CONDUCTIVITY DATA FOR TRAM TUFF WELDED LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tctm  Trammd
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
end template 9

OUTPUTFILE  vtramweldeddtc.dat
run template 9



start template 10
title DRY THERMAL CONDUCTIVITY DATA FOR TRAM TUFF NONWELDED LAYERS
colhead 1
colhead dry thermal conductivity
! dry thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    'Tct '  Tctuv  Tctuc  Tctlc  Tctlv  Tctbt  Tramuv  Tramuc  Tramlc
KEEP    Tramlv  Trambt
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  dry
```

```
end template 10

OUTPUTFILE  vtramnonweldeddtc.dat
run template 10



start template 11
title WET THERMAL CONDUCTIVITY DATA FOR WELDED LAYERS ABOVE CALICO HILLS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Qa  Tmr  Tpc_un  Tpk  Tptrn  Tptrl  'Tptp '  Tptf
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 11

OUTPUTFILE  vweldedwtc.dat
run template 11



start template 12
title WET THERMAL CONDUCTIVITY DATA FOR NON-WELDED LAYERS ABOVE CALICO HILLS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tpcrv3  Tpcpv1  Tpbt4  Tpy  Tpbt3  Tpp  Tpbt2  Tptrv3  Tptpv1  Tpbt1
KEEP    Pah     Yucca   Tpcpv2  Tptrv2  Tptpv2
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 12
```

```
OUTPUTFILE  vnonweldedwtc.dat
run template 12



start template 13
title WET THERMAL CONDUCTIVITY DATA FOR VITRIC LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tpcpv3   Tptrv1  Tptpv3
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 13

OUTPUTFILE  vvitricwtc.dat
run template 13



start template 14
title WET THERMAL CONDUCTIVITY DATA FOR CALICO LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tac   Tacbt  V-Z
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 14

OUTPUTFILE  vcalicowtc.dat
run template 14
```

```
start template 15
title WET THERMAL CONDUCTIVITY DATA FOR PROW PASS WELDED LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcpm   Prowmd
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 15

OUTPUTFILE  vprowweldedwtc.dat
run template 15



start template 16
title WET THERMAL CONDUCTIVITY DATA FOR PROW PASS NONWELDED LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcplc  Tcplv  Tcpuc  Tcpuv  Tcpbt  Prowuv  Prowuc  Prowlc  Prowlv
KEEP    Prowbt  Tcpbt   Tcp1   Tcp2   Tcp3   Tcp4
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 16

OUTPUTFILE  vprownonweldedwtc.dat
run template 16


start template 17
title WET THERMAL CONDUCTIVITY DATA FOR BULLFROG WELDED LAYERS
```

```
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcbm  Bullfrogmd   Tcb3   Tcb4
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 17

OUTPUTFILE  vbullfrogweldedwtc.dat
run template 17



start template 18
title WET THERMAL CONDUCTIVITY DATA FOR BULLFROG NONWELDED LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tcblv  Bullfroguv  Bullfroguc  Bullfroglc  Bullfroglv  Bullfrogbt
KEEP    Tcblc  Tcbuv  Tcbuc  Tcbbt   Tcb1   Tcb2
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 18

OUTPUTFILE  vbullfrognonweldedwtc.dat
run template 18


start template 19
title WET THERMAL CONDUCTIVITY DATA FOR TRAM TUFF WELDED LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
```

```
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    Tctm  Trammd
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 19

OUTPUTFILE  vtramweldedwtc.dat
run template 19

start template 20
title WET THERMAL CONDUCTIVITY DATA FOR TRAM TUFF NONWELDED LAYERS
colhead 1
colhead wet thermal conductivity
! wet thermal conductivity
field  out 1 8   in  1 8
!lithostratigraphy
field  out 11 18     in 11 18
KEEP    'Tct '  Tctuv  Tctuc  Tctlc  Tctlv  Tctbt  Tramuv  Tramuc  Tramlc
KEEP    Tramlv  Trambt
! location
field  out 21 40   in  21 40
!data source
field  out 45 54   in  datasource
!data row number
field  out 57 60   in  row
!temperature
field  out 63 66   in temp
!type (wet/dry):
field  out 69 72   in type
keep  wet
end template 20

OUTPUTFILE  vtramnonweldedwtc.dat
run template 20
```

Source: STN 10907-2.0-00 [DIRS 162673].

NOTES: 1. This appendix is a copy of data file *Inputs\QVTC\vtclayers.inp*, dated 3/26/03, 4:22PM, 12519 bytes.

2. Renamed program input files correspond to input files listed for Table 4-7

APPENDIX Q

EXCEL SPREADSHEET OF VALIDATION DRY THERMAL CONDUCTIVITY REGRESSION

Table Q-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*S00214_001.txt*
SNF40060298001.001 [DIRS 107372]	*S98430_001.txt*
SN0011T0571897.014 [DIRS 154449]	*s00441_001.txt*
SNL01A05059301.005 [DIRS 109002]	*s96370_001.txt*
SNL22100196001.006 [DIRS 158213]	*s98169_002.txt*
GS000408312231.004 [DIRS 149582]	*s00276_001.txt*
GS000508312231.006 [DIRS 153237]	*s00415_001.txt*
GS950308312231.002 [DIRS 108990]	*s96015_001.txt*
GS950408312231.004 [DIRS 108986]	*s96021_001.txt*
GS940508312231.006 [DIRS 107149]	*s96024_003.txt*
GS930108312231.006 [DIRS 108997]	*s96025_001.txt*
GS920508312231.012 [DIRS 109001]	*s96026_001.txt*
GS940408312231.004 [DIRS 109000]	*s96027_001.txt*
GS951108312231.009 [DIRS 108984]	*s96037_001.txt*
GS951108312231.011 [DIRS 108992]	*s96049_001.txt*
GS960808312231.004 [DIRS 108985]	*s97058_001.txt*
GS980708312242.010 [DIRS 106752]	*s98248_004.txt*
GS980808312242.014 [DIRS 106748]	*s98285_001.txt*
GS951108312231.010 [DIRS 108983]	*s96046_001.txt*
GS920408312314.011 [DIRS 129660]	*s97135_002.txt*
GS930408312132.007 [DIRS 129625]	*s97276_001.txt*
SNL01A05059301.007 [DIRS 108980]	*s98424_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_002.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_004.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_005.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_001.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_003.txt*
SNL02030193001.008 [DIRS 120597]	*s98486_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_004.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_001.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_004.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_001.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_004.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_001.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_004.txt*
SNL02030193001.007 [DIRS 120582]	*s99106_001.txt*

Table Q-1. Input DTN List (Continued)

DTN	Renamed Program Input File
SNL02030193001.014 [DIRS 109609]	*s99107_001.txt*
SNL02030193001.014 [DIRS 109609]	*s99107_004.txt*
SNL02030193001.015 [DIRS 120617]	*s99108_001.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_001.txt*
SNL02030193001.012 [DIRS 108416]	*s99110_001.txt*
SNL02030193001.022 [DIRS 109613]	*s99111_002.txt*
SNL02030193001.016 [DIRS 120619]	*s99112_001.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_001.txt*
SNL02030193001.018 [DIRS 109611]	*s99114_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_002.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_004.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_001.txt*
SNL01A05059301.002 [DIRS 150042]	*s99435_001.txt*
MO0012POROCHOL.000 [DIRS 153376]	*s00452_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_006.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_005.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_001.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_032.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_033.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_034.txt*
GS950308312231.002 [DIRS 108990]	*s96015_002.txt*
GS950408312231.004 [DIRS 108986]	*s96021_002.txt*
GS940508312231.006 [DIRS 107149]	*s96024_002.txt*
GS930108312231.006 [DIRS 108997]	*s96025_002.txt*
GS920508312231.012 [DIRS 109001]	*s96026_002.txt*
GS940408312231.004 [DIRS 109000]	*s96027_002.txt*
GS951108312231.009 [DIRS 108984]	*s96037_002.txt*
GS960808312231.004 [DIRS 108985]	*s97058_002.txt*
GS920408312314.011 [DIRS 129660]	*s97135_007.txt*
GS930408312132.007 [DIRS 129625]	*s97276_003.txt*
GS980708312242.010 [DIRS 106752]	*s98248_006.txt*
GS980808312242.014 [DIRS 106748]	*s98285_002.txt*
SNL02030193001.001 [DIRS 120572]	*s98483_001.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_005.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_005.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_002.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_003.txt*
SNL02030193001.028 [DIRS 159972]	*s99121_001.txt*

Table Q-2. Excel Spreadsheet of Regression Analysis

layer	kd	phi	drybd	1/phi	1/phi^2	dbd/(1-phi)	kd fit	relerr
welded	1.132	0.128	2190	7.8125	61.03516	2511.468	1.206793	0.066072
vitric	1.48	0.038	2310	26.3158	692.5208	2401.247	1.481068	0.000721
nonwelded	0.417	0.379	1460	2.63852	6.961801	2351.047	0.418815	0.004351
calico	0.577	0.282	1670	3.5461	12.57482	2325.905	0.538451	-0.06681
prow nw	0.652	0.267	1790	3.74532	14.02741	2442.019	0.647866	-0.00634
bull nw	0.7	0.22	1880	4.54545	20.66116	2410.256	0.738732	0.055332
bull weld	1.4	0.115	2260	8.69565	75.61437	2553.672	1.326276	-0.05266
RMSERR=	0.045862							
Coefficients:	A=	-1.65125	B=	0.18022	C=	-0.004726	D=	0.000692
Predictions:								
prow weld		0.194	2070	5.15464	26.57031	2568.238	0.929954	
tram nw		0.288	1760	3.47222	12.05633	2471.91	0.628654	
tram wel		0.184	2140	5.43478	29.53686	2622.549	1.004018	

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99347322
R Square	0.98698905
Adjusted R	0.9739781
Standard Er	0.06840338
Observation	7

ANOVA

	df	*SS*	*MS*	*F*
Regression	3	1.0648284	0.3549428	75.8583247
Residual	3	0.0140371	0.004679	
Total	6	1.0788654		

	Coefficients	Standard Er	t Stat	P-value
Intercept	-1.6512471	1.9223781	-0.8589606	0.45351945
X Variable 1	0.18022044	0.0499715	3.6064615	0.03659487
X Variable 2	-0.0047255	0.0016455	-2.871852	0.06395337
X Variable 3	0.00069222	0.0008673	0.7981024	0.48314726

NOTE: This appendix is a copy of data file *Outputs\TCRegression\drytcregression.xls*, dated 4/10/03, 2:57PM, 18432 bytes.

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APPENDIX R

EXCEL SPREADSHEET OF VALIDATION WET THERMAL CONDUCTIVITY REGRESSION

Table R-1. Input DTN List

DTN	Renamed Program Input File
MO0004QGFMPICK.000 [DIRS 152554]	*S00214_001.txt*
SNF40060298001.001 [DIRS 107372]	*S98430_001.txt*
SN0011T0571897.014 [DIRS 154449]	*s00441_001.txt*
SNL01A05059301.005 [DIRS 109002]	*s96370_001.txt*
SNL22100196001.006 [DIRS 158213]	*s98169_002.txt*
GS000408312231.004 [DIRS 149582]	*s00276_001.txt*
GS000508312231.006 [DIRS 153237]	*s00415_001.txt*
GS950308312231.002 [DIRS 108990]	*s96015_001.txt*
GS950408312231.004 [DIRS 108986]	*s96021_001.txt*
GS940508312231.006 [DIRS 107149]	*s96024_003.txt*
GS930108312231.006 [DIRS 108997]	*s96025_001.txt*
GS920508312231.012 [DIRS 109001]	*s96026_001.txt*
GS940408312231.004 [DIRS 109000]	*s96027_001.txt*
GS951108312231.009 [DIRS 108984]	*s96037_001.txt*
GS951108312231.011 [DIRS 108992]	*s96049_001.txt*
GS960808312231.004 [DIRS 108985]	*s97058_001.txt*
GS980708312242.010 [DIRS 106752]	*s98248_004.txt*
GS980808312242.014 [DIRS 106748]	*s98285_001.txt*
GS951108312231.010 [DIRS 108983]	*s96046_001.txt*
GS920408312314.011 [DIRS 129660]	*s97135_002.txt*
GS930408312132.007 [DIRS 129625]	*s97276_001.txt*
SNL01A05059301.007 [DIRS 108980]	*s98424_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_001.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_002.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_004.txt*
SNL02030193001.002 [DIRS 120575]	*s98484_005.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_001.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_003.txt*
SNL02030193001.008 [DIRS 120597]	*s98486_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_001.txt*
SNL02030193001.003 [DIRS 120578]	*s99100_004.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_001.txt*
SNL02030193001.006 [DIRS 120579]	*s99101_004.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_001.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_004.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_001.txt*
SNL02030193001.005 [DIRS 122545]	*s99105_004.txt*
SNL02030193001.007 [DIRS 120582]	*s99106_001.txt*

Table R-1. Input DTN List (Continued)

DTN	Renamed Program Input File
SNL02030193001.014 [DIRS 109609]	*s99107_001.txt*
SNL02030193001.014 [DIRS 109609]	*s99107_004.txt*
SNL02030193001.015 [DIRS 120617]	*s99108_001.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_001.txt*
SNL02030193001.012 [DIRS 108416]	*s99110_001.txt*
SNL02030193001.022 [DIRS 109613]	*s99111_002.txt*
SNL02030193001.016 [DIRS 120619]	*s99112_001.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_001.txt*
SNL02030193001.018 [DIRS 109611]	*s99114_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_001.txt*
SNL02030193001.019 [DIRS 108431]	*s99115_002.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_004.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_001.txt*
SNL01A05059301.002 [DIRS 150042]	*s99435_001.txt*
MO0012POROCHOL.000 [DIRS 153376]	*s00452_001.txt*
SNL02030193001.020 [DIRS 108432]	*s99116_006.txt*
SNL02030193001.021 [DIRS 108433]	*s99117_005.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_001.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_032.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_033.txt*
MO0109HYMXPROP.001 [DIRS 155989]	*s01144_034.txt*
GS950308312231.002 [DIRS 108990]	*s96015_002.txt*
GS950408312231.004 [DIRS 108986]	*s96021_002.txt*
GS940508312231.006 [DIRS 107149]	*s96024_002.txt*
GS930108312231.006 [DIRS 108997]	*s96025_002.txt*
GS920508312231.012 [DIRS 109001]	*s96026_002.txt*
GS940408312231.004 [DIRS 109000]	*s96027_002.txt*
GS951108312231.009 [DIRS 108984]	*s96037_002.txt*
GS960808312231.004 [DIRS 108985]	*s97058_002.txt*
GS920408312314.011 [DIRS 129660]	*s97135_007.txt*
GS930408312132.007 [DIRS 129625]	*s97276_003.txt*
GS980708312242.010 [DIRS 106752]	*s98248_006.txt*
GS980808312242.014 [DIRS 106748]	*s98285_002.txt*
SNL02030193001.001 [DIRS 120572]	*s98483_001.txt*
SNL02030193001.004 [DIRS 108415]	*s98485_005.txt*
SNL02030193001.013 [DIRS 120614]	*s99104_005.txt*
SNL02030193001.009 [DIRS 109614]	*s99109_002.txt*
SNL02030193001.017 [DIRS 109610]	*s99113_003.txt*
SNL02030193001.028 [DIRS 159972]	*s99121_001.txt*

Table R-2. Excel Spreadsheet of Regression Analysis

layer	kw	phi	drybd	1/phi	1/phi^2	dbd/(1-phi)	kd fit	relerr
welded	1.593	0.128	2190	7.8125	61.03516	2511.468	1.682987	0.056489
vitric	1.903	0.038	2310	26.3158	692.5208	2401.247	1.903189	9.92E-05
nonwelded	1.026	0.379	1460	2.63852	6.961801	2351.047	1.056249	0.029483
calico	1.162	0.282	1670	3.5461	12.57482	2325.905	1.135025	-0.023214
prow nw	1.258	0.267	1790	3.74532	14.02741	2442.019	1.252097	-0.004692
bull nw	1.33	0.22	1880	4.54545	20.66116	2410.256	1.308016	-0.01653
bull weld	1.85	0.115	2260	8.69565	75.61437	2553.672	1.784436	-0.03544
RMSERR=	0.029642							
Coefficients:	A=	-1.20708	B=	0.13024	C=	-0.00332	D=	0.000826
Predictions:								
prow weld		0.194	2070	5.15464	26.57031	2568.238	1.49827	
tram nw		0.288	1760	3.47222	12.05633	2471.91	1.247779	
tram wel		0.184	2140	5.43478	29.53686	2622.549	1.569778	

SUMMARY OUTPUT				
Regression Statistics				
Multiple R	0.98954035			
R Square	0.9791901			
Adjusted R :	0.9583802			
Standard Er	0.06965905			
Observation:	7			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	3	0.6849729	0.2283243	47.054053
Residual	3	0.0145571	0.0048524	
Total	6	0.69953		
	Coefficients	*tandard Errc*	*t Stat*	*P-value*
Intercept	-1.2070813	1.9576669	-0.6165918	0.58113587
X Variable 1	0.13024348	0.0508889	2.5593711	0.08325973
X Variable 2	-0.0033234	0.0016757	-1.9833011	0.1416023
X Variable 3	0.00082636	0.0008833	0.9355875	0.4185031

NOTE: This appendix is a copy of data file *Outputs\TCRegression\wettcregression.xls*, dated 4/10/03, 3:56PM, 18432 bytes.

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APPENDIX S

UNCERTAINTY ANALYSIS OF THERMAL CONDUCTIVITY OF NONREPOSITORY LITHOSTRATIGRAPHIC LAYERS

S1. UNCERTAINTY ANALYSIS OF THERMAL CONDUCTIVITY OF NONREPOSITORY LITHOSTRATIGRAPHIC LAYERS

S1.1 INTRODUCTION AND PURPOSE

This section develops a one-dimensional (1-D) steady-state calculation for heat flow through various layers above and below the repository, and then develops an uncertainty analysis of thermal conductivity of the nonrepository lithostratigraphic layers.

The calculation is then used to estimate the contribution to the variance of the temperature from the thermal conductivity for the nonrepository layers. The calculation compares these contributions to the variance of temperature from the thermal conductivity with the main repository layers for the prediction of the repository driftwall temperature.

The calculation then examines the effect of an increased porosity in the Tiva Canyon unit above the repository.

S2. CONCEPTUAL AND MATHEMATICAL MODEL DEVELOPMENT

This section develops the method for predicting temperature in the repository as a function of lithostratigraphic unit thermal conductivity, strata thickness, and repository heating (i.e., f (Kth, thickness, and q)). Noting the analogy between solving the 1-D heat conduction problem in accordance with Fourier's Law, and the fluid flow problem in accordance with Darcy's Law, an expression for the effective thermal conductivity for heat flow in series in the vertical direction (Freeze and Cherry 1979 [DIRS 101173], p. 34) is:

$$K_z = \frac{d}{\sum_{i=1}^{n} \frac{d_i}{K_i}} \qquad \text{(Eq. S-1)}$$

where:

Kz	=	Composite thermal conductivity (W/(m K)),
d	=	Overall thickness of a series of units,
di	=	Unit thickness of the ith unit, and
K_i	=	Thermal conductivity of the ith unit.
n	=	Number of Layers

Consider the simple node network in Figure S-1; the three nodes of this network correspond to the ground surface, the repository horizon, and the base of the 1-D model.

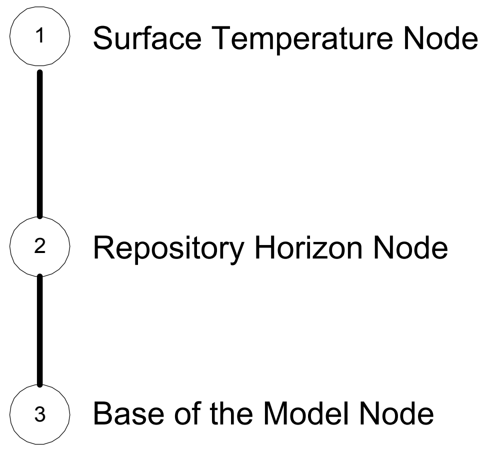


Figure S-1. Simple Lumped Parameter Model

Note that the effective thermal conductivity (Kth) above and below the repository can be provided. For above and below the repository horizon we have:

$$K_{12} = \frac{d_{12}}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} \qquad K_{32} = \frac{d_{32}}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}}$$

(Eq. S-2)

where:

K_{12}	=	Effective thermal conductivity from the repository horizon to the ground surface
K_{32}	=	Effective thermal conductivity from the repository horizon to the base of the model
d_{12}	=	Depth to the repository horizon from the ground surface, and
d_{32}	=	Depth from the repository horizon to the base of the 1-D model.
n1	=	Number of layers above the repository horizon
n2	=	Number of layers below the repository horizon

Let q_R equal the vertical heat flux at the repository horizon. The temperature response can be solved for by writing the general heat flow equation (Chapman 1974 [DIRS 152938], p. 173):

$$\sum_j \frac{\left(t_j - t_i\right)}{R_{ij}} + q_R = 0$$

(Eq. S-3)

Expanding this relationship at the repository horizon:

$$\frac{t_2 - t_1}{R_{12}} + \frac{t_2 - t_3}{R_{32}} + q_R = 0 \qquad \text{(Eq. S-4)}$$

where:

t_1 = Fixed temperature at the ground surface,
t_2 = Variable temperature at the repository horizon,
t_3 = Fixed temperature at the base of the model,
R_{12} = Resistance to heat flow from the repository horizon to the ground surface, and
R_{32} = Resistance to heat flow from the repository horizon to the base of the model.

Note that the resistances are given (Chapman 1974 [DIRS 152938], p. 173) as:

$$R_{12} = \frac{d_{12}}{K_{12} \cdot A_k} \qquad R_{32} = \frac{d_{32}}{K_{32} \cdot A_k} \qquad \text{(Eq. S-5)}$$

The solution to the steady-state heat conduction pertains to vertical flow from the repository. The resistances presented in Equation S-5 are for a unit area (the area for vertical heat flow (A_k) equals 1 m^2 for the SI system of units). Substituting in the formulas for the thermal conductivities:

$$R_{12} = \frac{d_{12}}{\dfrac{d_{12}}{\sum_{i=1}^{n1} \dfrac{d_i}{K_i}} \cdot 1} \qquad R_{32} = \frac{d_{32}}{\dfrac{d_{32}}{\sum_{i=1}^{n2} \dfrac{d'_i}{K'_i}} \cdot 1}$$

Simplifying:

$$R_{12} = \sum_{i=1}^{n1} \frac{d_i}{K_i} \qquad R_{32} = \sum_{i=1}^{n2} \frac{d'_i}{K'_i} \qquad \text{(Eq. S-6)}$$

$$\frac{t_2 - t_1}{\sum_{i=1}^{n1} \dfrac{d_i}{K_i}} + \frac{t_2 - t_3}{\sum_{i=1}^{n2} \dfrac{d'_i}{K'_i}} + q_R = 0 \qquad \text{(Eq. S-7)}$$

The analysis considers the change in temperature induced in the rock due to repository heating. The *In-Drift Natural Convection and Condensation* (BSC 2004 [DIRS 164327]) sets the temperature at the ground surface equal to ambient temperature, and shows that this temperature boundary condition is reasonable. For purposes of analysis, the temperature at the ground surface and at the greatest depth is set equal to zero. This is adequate for this analysis, because changes in temperature are of interest in this report.

$$\frac{t_2}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{t_2}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} + q_R = 0 \tag{Eq. S-8}$$

$$t_2 \cdot \left(\frac{1}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} \right) = -q_R \tag{Eq. S-9}$$

Factoring out the repository temperature:

$$t_2 = \frac{-q_R}{\left(\frac{1}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} \right)} \tag{Eq. S-10}$$

$$t_2 = -q_R \cdot \left(\frac{1}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} \right)^{-1} \tag{Eq. S-11}$$

S3. MATHEMATICAL UNCERTAINTY ANALYSIS

Hahn and Shapiro (1967 [DIRS 146529], p. 231) present the following relationship for the variance:

$$Var(z) = \sum_{i=1}^{n} \left(\frac{\partial h}{\partial x_i} \right)^2 \cdot Var(x_i) \tag{Eq. S-12}$$

Note that the measure for uncertainty in repository temperature is the standard deviation (or the square root of the variance). Note also that in the application of this equation to the prediction of temperature, h equals temperature at the repository horizon t_2, and x_i corresponds to thermal conductivity of each of the repository and nonrepository horizon units.

Equation S-12 provides information pertaining to the source of uncertainty from the individual variables. In Equation S-12, the variance of each individual variable (x_i) is multiplied by the square of the derivative of the system function for that parameter. The square of the derivative represents the sensitivity of the system variance to the individual parameter. If the sensitivity, and the variance, to an individual parameter, are large, then the system variance is dominated by this contribution. Conversely, if the sensitivity, and the variance, to an individual parameter are small, then the system variance is not influenced by this individual contribution.

Equation S-12 is applied to the calculation of the repository temperature as given by Equation S-10. The derivative of the temperature with respect to rock-mass thermal conductivity is determined for each of the layers.

In some applications, it may be necessary to have a measure of uncertainty that encompasses a larger fraction of the values than could reasonably be attributed to the measurement. If necessary, the user may multiply the standard uncertainty by a coverage factor to obtain an expanded uncertainty.

To factor the uncertainty, use a value of 1.96 from the table of percentage points for the Student's t distribution for a large number of measurements (Beyer 1987 [DIRS 103805], p. 571).

The 95-percent confidence interval is an appropriate range for this sensitivity study for two reasons:

1) Most of the model predictions fall within the 95-percent confidence interval, and

2) This study biases all of the thermal conductivities high, then low, to make bounding estimates of the effects to repository temperatures, although it would be a more realistic approach would be to let random variation occur across the thermal conductivity estimates.

Now consider the derivative with respect to thermal conductivity above the repository horizon. Consider the use of three layers, and then expand this expression for all layers.

Expanding Equation S-10 for three layers above and below the repository:

$$t_2 = -q_R \cdot \left(\frac{1}{\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}} + \frac{1}{\frac{d'_1}{K'_1} + \frac{d'_2}{K'_2} + \frac{d'_3}{K'_3}} \right)^{-1} \qquad \text{(Eq. S-13)}$$

where d_1, d_2, d_3, K_1, K_2, and K_3 refer to the layer thickness and thermal conductivity above the repository, respectively, and d'_1, d'_2, d'_3, K'_1, K'_2, and K'_3 are the comparable parameters below the repository.

Differentiation of Equation S-13 yields:

$$\frac{\partial}{\partial K_1} t_2 = \frac{q_R}{\left(\frac{1}{\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3}} + \frac{1}{\frac{d'_1}{K'_1} + \frac{d'_2}{K'_2} + \frac{d'_3}{K'_3}} \right)^2 \cdot \left(\frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3} \right)^2} \cdot \frac{d_1}{K_1^{\,2}}$$

(Eq. S-14)

or, writing for the general case for the influence of the effective thermal conductivity of the ith layer above the repository on the temperature of the repository:

$$\frac{\partial}{\partial K_i} t_2 = \frac{q_R}{\left(\frac{1}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} \right)^2 \cdot \left(\sum_{i=1}^{n1} \frac{d_i}{K_i} \right)^2} \cdot \frac{d_i}{K_i^{\,2}}$$

(Eq. S-15)

$$\frac{\partial}{\partial K_1} t_2 = \frac{q_R}{\left(\frac{1}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} \right)^2 \cdot \left(\sum_{i=1}^{n2} \frac{d'_i}{K'_i} \right)^2} \cdot \frac{d'_i}{K'^{\,2}_i}$$

(Eq. S-16)

S3.1 REPOSITORY PROPERTY VALUES ABOVE AND BELOW THE DISPOSAL HORIZON

In this section, thermal conductivity and thickness for lithostratigraphic layers above and below the repository are defined. The planned thermal load for the repository is also defined. These values will be used to calculate the repository temperatures and variances. The properties for thermal conductivity are obtained from Table 6-13 of this report, and presented in Table S-1.

The saturated thermal conductivities are used for this analysis because the matrix pore volume is generally close to saturation after 1,000 years, when heat has diffused into the nonrepository horizon units. The results of the *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]) show a high matrix saturation during this period for the repository horizon units. For example, matrix saturation is high at the repository horizon at locations P2ER8C6, P2WR8C8, P2WR5C10, and P3R7C12 (BSC 2004 [DIRS 169565], Figures 6.3-7 to 6.3-10) after 1,000 years for the mean and high infiltration cases. These results would provide a lower bound for matrix saturation for the nonrepository horizon units because the maximum extent of the dryout zone is only about 10 meters from the repository horizon (BSC 2004 [DIRS 169565]. In addition, the volumetric moisture content versus temperature relationship, as measured from neutron logging of Borehole 79 and Borehole 80 during the Drift Scale Test heating phase, shows little reduction in volumetric moisture content below the boiling point of water (DTN MO0406SEPTVDST.000 [DIRS 170616], file "*both.xls*").

The thickness of the layers is obtained from *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]) (for column P2WR5C10 as contained in Attachment V; this column is located at coordinates E170730.297 and N234912.719). The thermal conductivity at the repository horizon is obtained from *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Table 6-6). Note that the data are input from Table S-1.

Table S-1. Summary of Lithostratigraphic Units and Relevant Thermal Properties

	A	B	C	D	E	F	G	H	I	J	K
				Matrix Thermal Conductivity (W/(m K))[1,3]							
				Dry		Wet					
	GFM Unit[1]	Strat. Unit[2]	No. of Points[1]	mean	std dev	mean	std dev	Strat. Unit Thickness (m)[4]	Layer Type	Max. Relative Error[9]	Uncer-tainty (W/(m K))
3	Crystal-Rich Tiva/Post Tiva	tcw11	17	1.30	0.23	1.81	0.20	0.00	welded	1.96	0.38
4	Tpcp (2)	tcw12	17	1.30	0.23	1.81	0.20	0.00	welded	1.96	0.38
5	TpcLD (3)	tcw12	17	1.30	0.23	1.81	0.20	20.24	welded	1.96	0.38
6	Tpcpv3 (4)	tcw13[5]	2	0.59	0.19	0.93	0.20	4.01	vitric	1.96	0.39
7	Tpcpv2 (5)	tcw13[5]	2	0.59	0.19	0.93	0.20	0.00	non-welded	1.96	0.39
8	Tpcpv1(6)	ptn21	9	0.49	0.16	1.06	0.15	7.21	non-welded	1.96	0.29
9	Tpbt4 (7)	ptn22	9	0.49	0.16	1.06	0.15	5.60	non-welded	1.96	0.29
10	Yucca (8)	ptn23	9	0.49	0.16	1.06	0.15	2.02	non-welded	1.96	0.29
11	Tpbt3_dc (9)	ptn24	9	0.49	0.16	1.06	0.15	12.51	non-welded	1.96	0.29
12	Pah (10)	ptn25	9	0.49	0.16	1.06	0.15	36.50	non-welded	1.96	0.29
13	Tpbt2 (11)	ptn26	9	0.49	0.16	1.06	0.15	3.76	non-welded	1.96	0.29
14	Tptrv3 (12)	ptn26	9	0.49	0.16	1.06	0.15	3.76	non-welded	1.96	0.29
15	Tptrv2 (13)	ptn26	9	0.49	0.16	1.06	0.15	3.76	non-welded	1.96	0.29
16	Tptrv1 (14)	tsw31[6]	2	0.99	0.23	1.30	0.22	1.99	vitric	1.96	0.44

Table S-1. Summary of Lithostratigraphic Units and Relevant Thermal Properties (Continued)

	A	B	C	D	E	F	G	H	I	J	K
				Matrix Thermal Conductivity (W/(m K))[1,3]							Uncer-tainty (W/(mK))
				Dry		Wet					
	GFM Unit[1]	Strat. Unit[2]	No. of Points[1]	mean	std dev	mean	std dev	Strat. Unit Thickness (m)[4]	Layer Type	Max. Relative Error[9]	
17	Tptrn (15)	tsw32	17	1.30	0.23	1.81	0.20	45.59	welded	1.96	0.38
18	Tptrl (16)	tsw33	17	1.30	0.23	1.81	0.20	0.00	welded	1.96	0.38
19	Tptpul	tsw33	-	1.18	0.24	1.77	0.25	85.25	welded	1.96	0.48
20	Tptpmn	tsw34	-	1.42	0.27	2.07	0.25	32.95	welded	1.96	0.49
21	Tptpll above	tsw35 above	-	1.2784	0.2511	1.89	0.25	45.33	welded	1.96	0.49
22	Tptpll below	tsw35 below	-	1.28	0.25	1.89	0.25	59.39	welded	1.96	0.49
23	Tptpln	tsw36	-	1.49	0.28	2.13	0.27	25.83	welded	1.96	0.52
24	Tptpln	tsw37[7]	-	1.49	0.28	2.13	0.27	12.91	welded	1.96	0.52
25	Tptpv3 (18)	tsw38	2	0.69	0.23	0.80	0.25	21.90	vitric	1.96	0.49
26	Tptpv2(19)	tsw9z (tsw39)[8]	9	0.49	0.16	1.06	0.15	3.30	non-welded	1.96	0.29
27	Tptpv1(20)	ch1z	9	0.49	0.16	1.06	0.15	3.30	non-welded	1.96	0.29
28	Tpbt1	ch1z	9	0.49	0.16	1.06	0.15	15.04	non-welded	1.96	0.29
29	Calico	ch2z	5	0.60	0.11	1.26	0.14	20.29	calico	1.96	0.28
30	Calico	ch3z	5	0.60	0.11	1.26	0.14	20.30	calico	1.96	0.28
31	Calico	ch4z	5	0.60	0.11	1.26	0.14	20.27	calico	1.96	0.28
32	Calico	ch5z	5	0.60	0.11	1.26	0.14	20.30	calico	1.96	0.28
33	Calicobt	ch6z	5	0.60	0.11	1.26	0.14	17.58	calico	1.96	0.28
34	Prowuv	pp4	9	0.57	0.10	1.13	0.12	19.69	Prow Pass non-welded	1.96	0.24

Table S-1. Summary of Lithostratigraphic Units and Relevant Thermal Properties (Continued)

	A	B	C	D	E	F	G	H	I	J	K
				Matrix Thermal Conductivity (W/(m K))[1,3]							Uncer-tainty (W/(mK))
				Dry		Wet					
	GFM Unit[1]	Strat. Unit[2]	No. of Points[1]	mean	std dev	mean	std dev	Strat. Unit Thickness (m)[4]	Layer Type	Max. Relative Error[9]	
35	Prowuc	pp3	9	0.57	0.10	1.13	0.12	14.33	Prow Pass non-welded	1.96	0.24
36	Prowmd	pp2	17	1.06	0.18	1.63	0.17	4.10	welded	1.96	0.33

1 Thermal conductivities are obtained from Table 6-13 of this report.
2 Lithostratigraphic units are obtained from Table IV-3a of the *Multiscale Thermohydrologic Model* (BSC 2004) [DIRS 169565].
3 Thermal conductivities for the repository units are obtained from Table 6-6 of the *Thermal Conductivity of the Potential Horizon* (BSC 2004 [DIRS 169854]).
4 See Table IV-3a of the *Multiscale Thermohydrologic Model* (BSC 2004) [DIRS 169565].
5 The thermal properties for tsw13 are obtained from the average for GFM units Tpcpv3(4) and Tpcpv2(5) from Table 6-13 based upon the correlation presented in Table 4-10 of the *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]).
6 The thermal properties for tsw31 are obtained from the average for GFM units Tptrv1(14) and Tptrn(15) from Table 6-13 based upon the correlation presented in Table 4-10 of the *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]).
7 Tsw37 has the same thermal properties as the Tptpln unit.
8 Tsw9v is identified as tsw39 in Table 4-10 of the *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]).
9 To factor the uncertainty, use a value of 1.96 from the table of percentage points for the Student's t distribution for a large number of measurements (Beyer, W.H., ed. 1987. *CRC Standard Mathematical Tables*, p. 571) [DIRS 103805].

Extract the depths above the repository horizon. Referring to Table S-1, the submatrix function is used for the extraction. The submatrix function will extract a submatrix from a beginning row (Table S-1) to an ending row, and a beginning column to an ending column.

The data for the depths above the repository horizon begin at row 3, and end at row 21. The stratigraphic unit thickness data are in column H. Thus, the submatrix is a vector, and the function is evaluated submatrix (Strat, beginning row, ending row, beginning column, ending column):

$$d := \mathrm{submatrix}(\mathrm{Strat}, 3, 21, 8, 8)\cdot \mathrm{m}$$

Now, as shown in Table S-2, extract the data from below the repository horizon. Again, the submatrix function is used with the beginning row at 22 to 36. The thickness data are again in Table S-1, column H.

$$d' := \mathrm{submatrix}(\mathrm{Strat}, 22, 36, 8, 8)\cdot \mathrm{m}$$

Table S-2. Unit Thicknesses Above and Below the Repository Horizon

Above the Repository Horizon

d = (m)

	1
1	0
2	0
3	20.24
4	4.01
5	0
6	7.21
7	5.6
8	2.02
9	12.51
10	36.5
11	3.76
12	3.76
13	3.76
14	1.99
15	45.59
16	0
17	85.25
18	32.95
19	45.33

Below the Repository Horizon

d' = (m)

	1
1	59.39
2	25.83
3	12.91
4	21.9
5	3.3
6	3.3
7	15.04
8	20.29
9	20.3
10	20.27
11	20.3
12	17.58
13	19.69
14	14.33
15	4.1

Assign the number of units above and below the repository.

$n1 := \text{rows}(d)$ $\quad$ $n2 := \text{rows}(d')$

$n1 = 19$ $\quad$ $n2 = 15$

Calculate the thickness d_{12} and d_{32} above and below the repository.

$$d_{12} := \sum_{i=1}^{n1} d_i \qquad d_{12} = 310.49\text{m}$$

$$d_{32} := \sum_{i=1}^{n2} d'_i \qquad d_{32} = 278.53\text{m}$$

NOTE: In MathCad 11 a **:=** symbol is an assignment statement for a function or a variable.

An extraction of the thermal conductivity for the wet case above and below the repository is shown in Table S-3. In this case, the submatrix command from the same rows as above is made, but with column F of Table S-1 (saturated thermal conductivity data):

$$K := \text{submatrix}(\text{Strat}, 3, 21, 6, 6)\cdot\frac{W}{m\cdot K} \qquad K' := \text{submatrix}(\text{Strat}, 22, 36, 6, 6)\cdot\frac{W}{m\cdot K}$$

NOTE: In MathCad 11 a **:=** symbol is an assignment statement for a function or a variable.

Table S-3. Saturated Thermal Conductivities Above and Below the Repository Horizon

Above the Repository Horizon

$K =$ (units: $\frac{W}{m\cdot K}$)

	1
1	1.81
2	1.81
3	1.81
4	0.93
5	0.93
6	1.06
7	1.06
8	1.06
9	1.06
10	1.06
11	1.06
12	1.06
13	1.06
14	1.3
15	1.81
16	1.81
17	1.77
18	2.07
19	1.89

Below the Repository Horizon

$K' =$ (units: $\frac{W}{m\cdot K}$)

	1
1	1.89
2	2.13
3	2.13
4	0.8
5	1.06
6	1.06
7	1.06
8	1.26
9	1.26
10	1.26
11	1.26
12	1.26
13	1.13
14	1.13
15	1.63

S3.2 AVERAGE WASTE PACKAGE HEAT LOADING

To input the average line loading at the repository horizon, the line averaged powers are obtained from *D&E/PA/C IED Typical Waste Package Components Assembly* (BSC 2004 [DIRS 167754]). This line load includes the net influence of ventilation on the waste package load thermal output. The complete dataset is presented in Table S-4.

Table S-4. Average Line Load

Time (yr)	Line Load Power (W/m)	Line Load Power (W/m) with Ventilation
0.001	1.450E+03	2.030E+02
1	1.399E+03	1.958E+02
2	1.357E+03	1.899E+02
3	1.321E+03	1.849E+02
4	1.289E+03	1.804E+02
5	1.259E+03	1.763E+02
6	1.232E+03	1.724E+02
7	1.206E+03	1.688E+02
8	1.181E+03	1.653E+02
9	1.157E+03	1.620E+02
10	1.135E+03	1.589E+02
11	1.110E+03	1.554E+02
12	1.088E+03	1.523E+02
13	1.068E+03	1.495E+02
14	1.049E+03	1.469E+02
15	1.033E+03	1.446E+02
16	1.012E+03	1.417E+02
17	9.934E+02	1.391E+02
18	9.759E+02	1.366E+02
19	9.595E+02	1.343E+02
20	9.443E+02	1.322E+02
21	9.267E+02	1.297E+02
22	9.103E+02	1.274E+02
23	8.950E+02	1.253E+02
24	8.805E+02	1.233E+02
25	8.666E+02	1.213E+02
26	8.525E+02	1.194E+02
27	8.382E+02	1.173E+02
28	8.245E+02	1.154E+02
29	8.114E+02	1.136E+02
30	7.992E+02	1.119E+02
31	7.858E+02	1.100E+02
32	7.730E+02	1.082E+02
33	7.610E+02	1.065E+02
34	7.493E+02	1.049E+02
35	7.381E+02	1.033E+02
36	7.262E+02	1.017E+02
37	7.150E+02	1.001E+02

Time (yr)	Line Load Power (W/m)	Line Load Power (W/m) with Ventilation
38	7.042E+02	9.859E+01
39	6.938E+02	9.713E+01
40	6.838E+02	9.573E+01
41	6.733E+02	9.426E+01
42	6.632E+02	9.284E+01
43	6.535E+02	9.148E+01
44	6.441E+02	9.018E+01
45	6.351E+02	8.892E+01
46	6.258E+02	8.762E+01
47	6.169E+02	8.637E+01
48	6.083E+02	8.517E+01
49	6.000E+02	8.400E+01
50	5.920E+02	8.287E+01
50.5	5.920E+02	3.400E+01
51	5.837E+02	5.837E+02
52	5.757E+02	5.757E+02
53	5.679E+02	5.679E+02
54	5.603E+02	5.603E+02
55	5.531E+02	5.531E+02
56	5.457E+02	5.457E+02
57	5.384E+02	5.384E+02
58	5.315E+02	5.315E+02
59	5.247E+02	5.247E+02
60	5.182E+02	5.182E+02
61	5.115E+02	5.115E+02
62	5.050E+02	5.050E+02
63	4.988E+02	4.988E+02
64	4.926E+02	4.926E+02
65	4.868E+02	4.868E+02
66	4.808E+02	4.808E+02
67	4.750E+02	4.750E+02
68	4.694E+02	4.694E+02
69	4.639E+02	4.639E+02
70	4.586E+02	4.586E+02
71	4.533E+02	4.533E+02
72	4.481E+02	4.481E+02
73	4.430E+02	4.430E+02
74	4.381E+02	4.381E+02

Table S-4. Average Line Load (Continued)

Time (yr)	Line Load Power (W/m)	Line Load Power (W/m) with Ventilation
75	4.333E+02	4.333E+02
76	4.285E+02	4.285E+02
77	4.238E+02	4.238E+02
78	4.192E+02	4.192E+02
79	4.148E+02	4.148E+02
80	4.104E+02	4.104E+02
81	4.061E+02	4.061E+02
82	4.019E+02	4.019E+02
83	3.978E+02	3.978E+02
84	3.938E+02	3.938E+02
85	3.898E+02	3.898E+02
86	3.859E+02	3.859E+02
87	3.822E+02	3.822E+02
88	3.784E+02	3.784E+02
89	3.748E+02	3.748E+02
90	3.713E+02	3.713E+02
91	3.678E+02	3.678E+02
92	3.644E+02	3.644E+02
93	3.611E+02	3.611E+02
94	3.578E+02	3.578E+02
95	3.546E+02	3.546E+02
96	3.515E+02	3.515E+02
97	3.484E+02	3.484E+02
98	3.454E+02	3.454E+02
99	3.425E+02	3.425E+02
100	3.396E+02	3.396E+02
110	3.142E+02	3.142E+02
120	2.927E+02	2.927E+02
130	2.742E+02	2.742E+02
140	2.583E+02	2.583E+02
150	2.443E+02	2.443E+02
160	2.335E+02	2.335E+02
170	2.239E+02	2.239E+02
180	2.152E+02	2.152E+02
190	2.074E+02	2.074E+02
200	2.002E+02	2.002E+02
250	1.752E+02	1.752E+02
300	1.578E+02	1.578E+02
350	1.444E+02	1.444E+02
400	1.334E+02	1.334E+02
450	1.240E+02	1.240E+02
500	1.159E+02	1.159E+02
550	1.087E+02	1.087E+02
600	1.022E+02	1.022E+02
650	9.647E+01	9.647E+01
700	9.122E+01	9.122E+01
750	8.643E+01	8.643E+01
800	8.202E+01	8.202E+01
850	7.800E+01	7.800E+01
900	7.428E+01	7.428E+01
950	7.088E+01	7.088E+01
1000	6.767E+01	6.767E+01
1500	4.666E+01	4.666E+01
2000	3.660E+01	3.660E+01
2500	3.154E+01	3.154E+01
3000	2.874E+01	2.874E+01
3500	2.695E+01	2.695E+01
4000	2.569E+01	2.569E+01
4500	2.466E+01	2.466E+01
5000	2.375E+01	2.375E+01
5500	2.292E+01	2.292E+01
6000	2.212E+01	2.212E+01
6500	2.139E+01	2.139E+01
7000	2.070E+01	2.070E+01
7500	2.002E+01	2.002E+01
8000	1.938E+01	1.938E+01
8500	1.877E+01	1.877E+01
9000	1.820E+01	1.820E+01
9500	1.763E+01	1.763E+01
10000	1.708E+01	1.708E+01
15000	1.284E+01	1.284E+01
20000	9.955E+00	9.955E+00
25000	7.984E+00	7.984E+00
30000	6.578E+00	6.578E+00
35000	5.518E+00	5.518E+00
40000	4.721E+00	4.721E+00
45000	4.075E+00	4.075E+00
50000	3.582E+00	3.582E+00

Table S-4. Average Line Load (Continued)

Time (yr)	Line Load Power (W/m)	Line Load Power (W/m) with Ventilation
55000	3.166E+00	3.166E+00
60000	2.808E+00	2.808E+00
65000	2.526E+00	2.526E+00
70000	2.279E+00	2.279E+00
75000	2.068E+00	2.068E+00
80000	1.880E+00	1.880E+00
85000	1.728E+00	1.728E+00
90000	1.616E+00	1.616E+00
95000	1.504E+00	1.504E+00
100000	1.387E+00	1.387E+00
150000	9.522E-01	9.522E-01
200000	8.589E-01	8.589E-01
250000	8.389E-01	8.389E-01
300000	8.203E-01	8.203E-01
350000	7.945E-01	7.945E-01
400000	7.746E-01	7.746E-01
450000	7.555E-01	7.555E-01
500000	6.960E-01	6.960E-01
550000	6.772E-01	6.772E-01
600000	6.574E-01	6.574E-01
650000	6.389E-01	6.389E-01
700000	6.139E-01	6.139E-01
750000	5.957E-01	5.957E-01
800000	5.769E-01	5.769E-01
850000	5.589E-01	5.589E-01
900000	5.350E-01	5.350E-01
950000	5.172E-01	5.172E-01
1000000	4.992E-01	4.992E-01

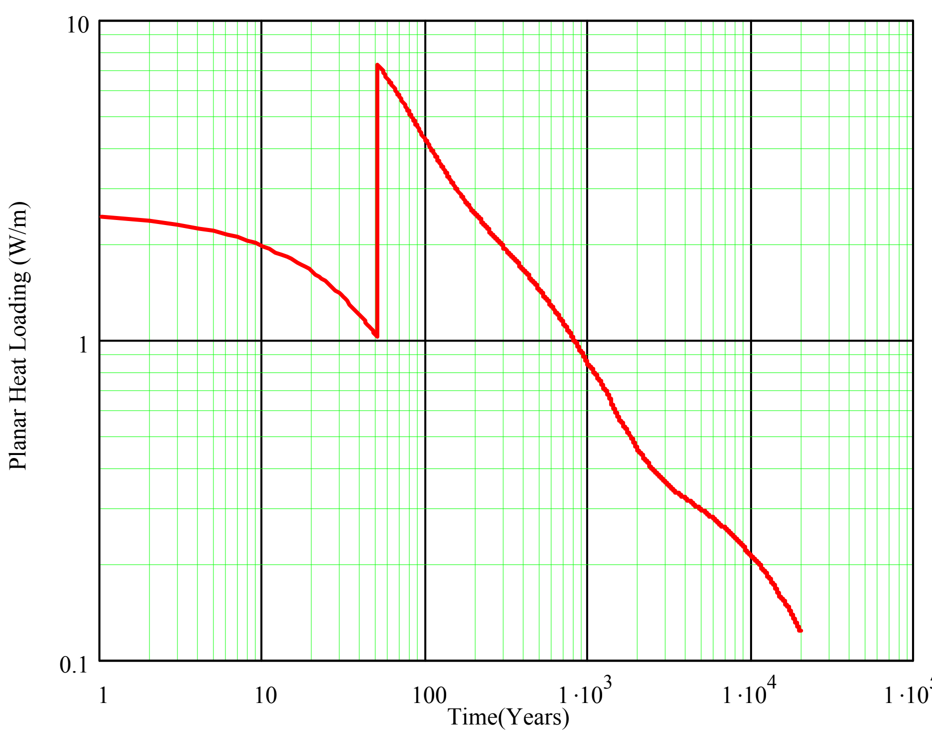
The ventilation efficiency used in the analysis is 86 percent for a 50-year period for an 800-m drift as presented in *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Table 8-3).

To assign the function for the calculation of the average planar heat flux, note that line load must be divided by the waste package spacing of 81 m (BSC 2004 [DIRS 168489], Table 1) to express the heat flux in the vertical direction. Note that in MathCad 11 a := symbol is an assignment statement for a function or a variable. The heat loading function (see Figure S-2) that is defined using the MathCad linear interpolation function has the form q(t)=linterp(QLoad<1> =x ,QLoad<3> =y,t) where x is the interpolation vector in time, y is the heat loading interpolation vector, and t is the time at which the interpolation function is evaluated.

$$q_R(t) := \mathrm{linterp}\left(QLoad^{\langle 1\rangle}, QLoad^{\langle 3\rangle}, t\right)\cdot\frac{\frac{W}{m}}{81\cdot m}$$

Plot the planar heat loading as a function of time in years.

$$t := 1, 2 .. 20000$$



Sources: *D&E / PA/C IED Typical Waste Package Components Assembly* (BSC 2004 [DIRS 167754]); *D&E / PA/C IED Emplacement Drift Configuration and Environment* (BSC 2004 [DIRS 168489], Table 1).

Note: Average waste package line load is reduced by 86% from 0 to 50 years to account for the effect of ventilation.

Figure S-2. Average Waste Package Line Loading

Because the analysis examines the change in temperature, the initial temperatures can be set to zero, and the change in temperature can then be calculated. The change in temperature can then be added to the initial temperature.

S4. PREDICTION OF TEMPERATURE AT THE REPOSITORY HORIZON UNDER STEADY-STATE CONDITIONS

The prediction of repository temperatures for postclosure analysis considers time-dependent heat diffusion through the media. With the analysis presented below, the steady-state solution should tend to overpredict the influence of the nonrepository horizon units. This approach is adequate for the purpose of this analysis.

Calculating the effective thermal conductivities shown in Equation S-18 for the saturated case gives the values (see Equation S-2):

$$\frac{d_{12}}{\left(\sum_{i=1}^{n1} \frac{d_i}{K_i}\right)} = 1.54\frac{W}{m\cdot K} \qquad \frac{d_{32}}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}} = 1.34\frac{W}{m\cdot K}$$

(Eq. S-17)

The function to predict repository driftwall temperature is based upon Equation S-10 is presented in Equation S-19.

$$t_2(t) := \frac{q_R(t)}{\dfrac{1}{\left(\sum_{i=1}^{n1} \frac{d_i}{K_i}\right)} + \dfrac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}}}$$

(Eq. S-18)

Plotting the base-case temperature as a function of time from 500 years to 2,000 years, Figure S-3 is generated. Note that after about 500 years, heat has diffused away from the repository horizon units into the nonrepository horizon units.

$$t := 500, 501 .. 20000$$

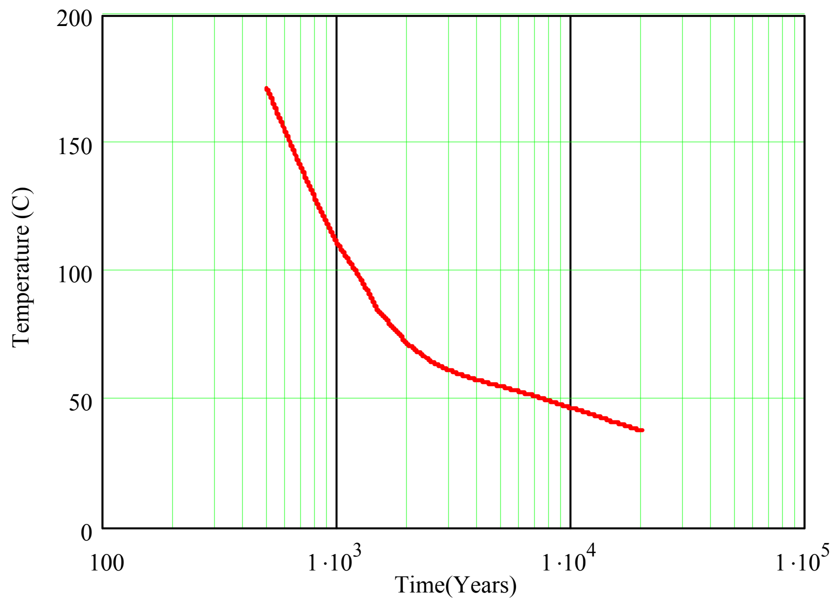


Figure S-3. Prediction of Temperature with Time for the Quasi–Steady-State Model

S5. UNCERTAINTY ANALYSIS TEMPERATURE RESULTS FROM THE STEADY-STATE SOLUTION

In Section S4, the repository temperature, as a function of time, was shown. The following analysis evaluates the impact of uncertainty in the thermal conductivity (Kth) for each of the units on this temperature distribution. The analysis will be done using Equation S-13 as presented by Hahn and Shapiro (1967 [DIRS 146529], p. 231). As discussed above, the uncertainty of the thermal conductivity for each of the lithostratigraphic units that is related to the square root of the variance will be represented by the standard deviation associated with the thermal conductivity predictions multiplied by a factor of 1.96.

The calculation reflects the exponential decay of heat. Extracting the standard deviation from the summary data in Table 6-13 yields the data arrays shown in Table S-5. The submatrix function is used with the same beginning and ending rows in column K of Table S-1.

$$\sigma := \text{submatrix}(\text{Strat}, 3, 21, 11, 11) \cdot \frac{W}{m \cdot K} \qquad \sigma' := \text{submatrix}(\text{Strat}, 22, 36, 11, 11) \cdot \frac{W}{m \cdot K}$$

Table S-5. Uncertainty in Saturated Thermal Conductivity Above and Below the Repository Horizon

Above the Repository Horizon

$\sigma =$ (units: $\frac{W}{m \cdot K}$)

	1
1	0.38
2	0.38
3	0.38
4	0.39
5	0.39
6	0.29
7	0.29
8	0.29
9	0.29
10	0.29
11	0.29
12	0.29
13	0.29
14	0.44
15	0.38
16	0.38
17	0.48
18	0.49
19	0.49

Below the Repository Horizon

$\sigma' =$ (units: $\frac{W}{m \cdot K}$)

	1
1	0.49
2	0.52
3	0.52
4	0.49
5	0.29
6	0.29
7	0.29
8	0.28
9	0.28
10	0.28
11	0.28
12	0.28
13	0.24
14	0.24
15	0.33
16	
17	
18	

Note that the solution to the sensitivity (or the partial derivatives) as represented by Equations S-15 and S-16 contains several summations that are constant for the analysis. In order to simplify the solution, the following constant terms (Term1, Term2, and Term12) are defined:

$$\mathrm{Term1} := \left(\sum_{i=1}^{n1} \frac{d_i}{K_i}\right)^2 \qquad \mathrm{Term1} = 4.04 \times 10^4 \, \frac{s^6 K^2}{kg^2}$$

(Eq. S-19)

$$\mathrm{Term2} := \left(\sum_{i=1}^{n2} \frac{d'_i}{K'_i}\right)^2 \qquad \mathrm{Term2} = 4.34 \times 10^4 \, \frac{s^6 K^2}{kg^2}$$

(Eq. S-20)

$$\mathrm{Term12} := \left(\frac{1}{\sum_{i=1}^{n1} \frac{d_i}{K_i}} + \frac{1}{\sum_{i=1}^{n2} \frac{d'_i}{K'_i}}\right)^2 \qquad \mathrm{Term12} = 9.55 \times 10^{-5} \, \frac{kg^2}{s^6 K^2}$$

(Eq. S-21)

Now substitute the constant terms into expressions into the partial derivatives in Equations S-15 and S-16:

$$\frac{\partial}{\partial K_i} t_2 = \frac{q_R}{Term12 \cdot Term1} \cdot \frac{d_i}{\left(K_i\right)^2}$$

(Eq. S-22)

$$\frac{\partial}{\partial K'_i} t_2 = \frac{q_R}{Term12 \cdot Term2} \cdot \frac{d'_i}{\left(K'_i\right)^2}$$

(Eq. S-23)

Now form the sum for the variances that are consistent with Equation S-12.

$$Var = \sum_{i=1}^{n1} \left[\left[\frac{q_R}{Term12 \cdot Term1} \cdot \frac{d_i}{\left(K_i\right)^2} \right]^2 \cdot \left(\sigma_i\right)^2 \right] + \sum_{i=1}^{n2} \left[\left[\frac{q_R}{Term12 \cdot Term2} \cdot \frac{d'_i}{\left(K'_i\right)^2} \right]^2 \cdot \left(\sigma'_i\right)^2 \right]$$

(Eq. S-24)

Now define a function that expresses the uncertainty in the waste package heat loading.

$$Vart(t) := \sum_{i=1}^{n1} \left[\left[\frac{q_R(t)}{Term12 \cdot Term1} \cdot \frac{d_i}{\left(K_i\right)^2} \right]^2 \cdot \left(\sigma_i\right)^2 \right] + \sum_{i=1}^{n2} \left[\left[\frac{q_R(t)}{Term12 \cdot Term2} \cdot \frac{d'_i}{\left(K'_i\right)^2} \right]^2 \cdot \left(\sigma'_i\right)^2 \right]$$

(Eq. S-25)

The range of uncertainty as a function of time is plotted in Figure S-4. The solid line represents the mean temperature prediction. The dotted line represents the mean temperature plus or minus one standard deviation (square root of the variance from Equation S-25). Figure S-5 displays results of the analysis and indicates that the temperature uncertainty is small. The uncertainty is 7 degrees Celsius after 800 years. The uncertainty is an overestimate because the more remote lithostratigraphic units will not influence repository temperature until sometime after waste emplacement, because of the time required for the heat to propagate to the remote nonrepository horizon units.

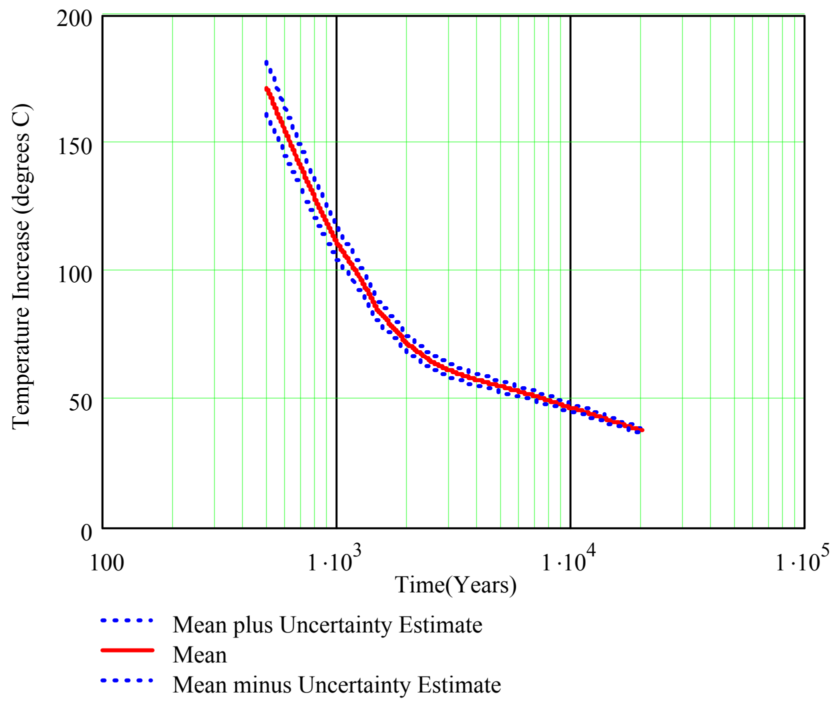


Figure S-4. Prediction of Temperature Range with Time for the Steady State Analysis

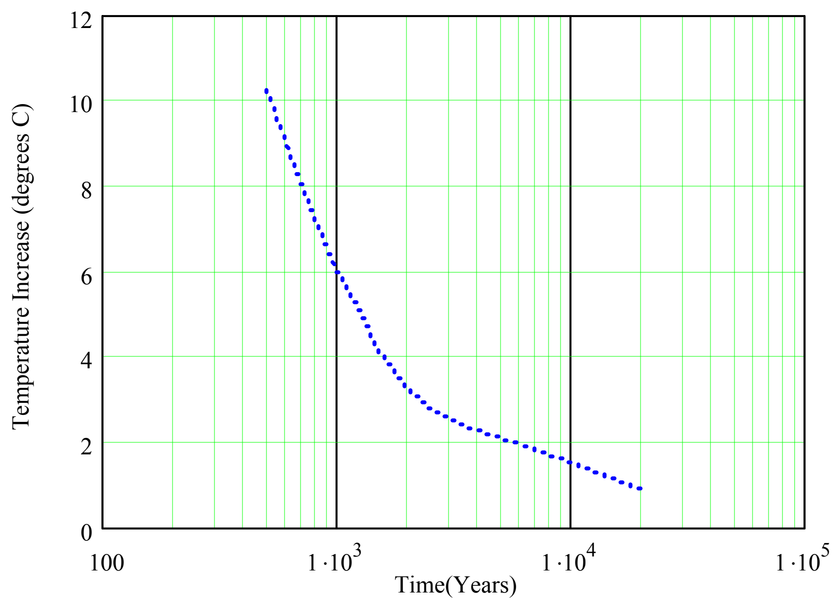


Figure S-5. Uncertainty as a Function of Time

Calculating the contribution to variance for the various layers at 500 years (a representative time), the percentage contribution to variance for each of the thermal conductivities is:

Above the repository horizon.

$i := 1..n1$

$$\mathrm{VectorA}_i := \left[\left[\frac{q_R(500)}{\mathrm{Term12}\cdot\mathrm{Term1}}\cdot\frac{d_i}{\left(K_i\right)^2}\right]^2\cdot\left(\sigma_i\right)^2\right]$$

Below the repository horizon.

$j := 1..n2$

$$\mathrm{VectorB}_j := \left[\left[\frac{q_R(500)}{\mathrm{Term12}\cdot\mathrm{Term2}}\cdot\frac{d'_j}{\left(K'_j\right)^2}\right]^2\cdot\left(\sigma'_j\right)^2\right]$$

(Eq. S-26)

Use the MathCad function "stack" to form a single vector from the ground surface to the base of the model. "Vector =: stack" means to form a single vector with Vector A above and Vector B below columnwise.

$$\mathrm{Vector} := \mathrm{stack}(\mathrm{VectorA}, \mathrm{VectorB})$$

(Eq. S-27)

The results of the analysis are output in Table S-6.

Table S-6. Contribution of Variance of Temperature from the Thermal Conductivity of Each Lithostratigraphic Unit

Lithostratigraphic Unit	Change in Temperature (C)	Percent Contribution
Crystal-Rich Tiva/Post Tiva	0.00	0.00%
Tpcp (2)	0.00	0.00%
TpcLD (3)	0.77	0.73%
Tpcpv3 (4)	0.45	0.43%
Tpcpv2 (5)	0.00	0.00%
Tpcpv1(6)	0.46	0.44%
Tpbt4 (7)	0.28	0.27%
Yucca (8)	0.04	0.03%
Tpbt3_dc (9)	1.39	1.33%
Pah (10)	11.88	11.36%
Tpbt2 (11)	0.13	0.12%
Tptrv3 (12)	0.13	0.12%
Tptrv2 (13)	0.13	0.12%
Tptrv1 (14)	0.04	0.03%
Tptrn (15)	3.89	3.72%
Tptrl (16)	0.00	0.00%

Table S-6. Contribution of Variance of Temperature from the Thermal Conductivity of Each Lithostratigraphic Unit (Continued)

Lithostratigraphic Unit	Change in Temperature (C)	Percent Contribution
Tptpul	23.66	22.64%
Tptpmn	1.96	1.88%
Tptpll above	5.25	5.02%
Tptpll below	7.80	7.46%
Tptpln	1.06	1.01%
Tptpln	0.26	0.25%
Tptpv3 (18)	33.44	32.00%
Tptpv2(19)	0.09	0.08%
Tptpv1(20)	0.09	0.08%
Tpbt1	1.84	1.76%
Calico	1.48	1.42%
Calico	1.49	1.42%
Calico	1.48	1.42%
Calico	1.49	1.42%
Calicobt	1.11	1.07%
Prowuv	1.56	1.50%
Prowuc	0.83	0.79%
Prowmd	0.03	0.03%
Total	104.50	100.00%

These results show that the primary contributions to temperature prediction variances originate with uncertainties in the Tptpv3 unit.

S6. INFLUENCE OF HIGH POROSITY ZONES IN THE TIVA CANYON

Thermal conductivity in the welded tuffs of the Tiva Canyon are influenced by zones of lithophysal porosity. The quasi–steady-state can be used to assess the influence of including a lithophysal porosity on thermal conductivity (1.81 W/(m K) (see Table 6-13)).

$$\mathrm{Strat}_{5,6} = 1.81$$

Now, consider that this value would be lower due to the air porosity effects. Assume a porosity of 20 percent, and calculate the reduction in rock-mass thermal conductivity. *Thermal Conductivity of the Potential Repository Horizon* (BSC 2004 [DIRS 169854], Section 6.1.8), states that it was found that the parallel or the volumetric averaging model applied to the calculation of bulk or rock-mass thermal conductivity. The reported value for the thermal conductivity of air is 0.01615*BTU/(hr*ft*R), which equals 0.028 W/(m K) at 50°C or 120°F (Chapman 1974 [DIRS 152938], p. 593).

$$\mathrm{Strat}_{5,6} := (1-0.2)\cdot 1.81 + 0.2\cdot 0.028 \qquad \mathrm{Strat}_{5,6} = 1.45$$

Now extract the thermal conductivity for the wet case above and below the repository.

$$K := \mathrm{submatrix}(\mathrm{Strat},3,21,6,6)\cdot\frac{W}{m\cdot K} \qquad K' := \mathrm{submatrix}(\mathrm{Strat},22,36,6,6)\cdot\frac{W}{m\cdot K}$$

The function for repository driftwall temperature based upon Equation S-10 is shown below in Equation S-19.

$$t_3(t) := \frac{q_R(t)}{\dfrac{1}{\left(\displaystyle\sum_{i=1}^{n1}\frac{d_i}{K_i}\right)} + \dfrac{1}{\displaystyle\sum_{i=1}^{n2}\frac{d'_i}{K'_i}}} \qquad \text{(Eq. S-28)}$$

A plot of the base-case temperature as a function of time is shown in Figure S-6, and compared to the base-case prediction shown in Figure S-3.

$$t_2(800) = 103.61\mathrm{K}$$

$$t := 500, 501 .. 20000$$

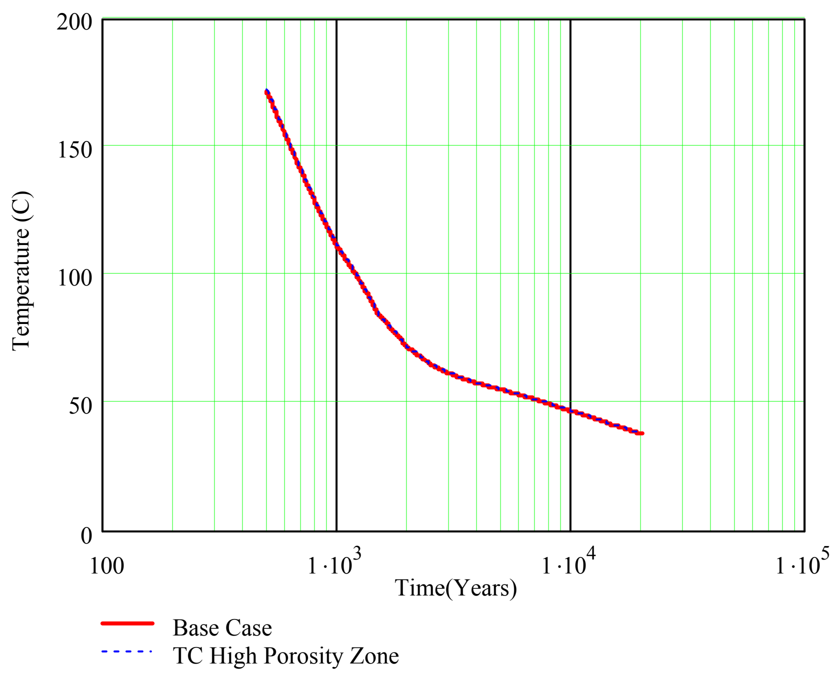


Figure S-6. Quasi–Steady-State Analysis for Variations in the Tiva Canyon Thermal Conductivity Over 20,000 Years

Take 500 years and calculate the contribution to variance for the various layers.

$i := 1..n1 \qquad j := 1..n2 \qquad n2 = 15$

$$\mathrm{VectorA}_i := \left[\left[\frac{q_R(500)}{\mathrm{Term12}\cdot\mathrm{Term1}}\cdot\frac{d_i}{\left(K_i\right)^2}\right]^2\cdot\left(\sigma_i\right)^2\right] \qquad \mathrm{VectorB}_j := \left[\left[\frac{q_R(500)}{\mathrm{Term12}\cdot\mathrm{Term2}}\cdot\frac{d'_j}{\left(K'_j\right)^2}\right]^2\cdot\left(\sigma'_j\right)^2\right]$$

$$\mathrm{Vector} := \mathrm{stack}(\mathrm{VectorA}, \mathrm{VectorB}) \qquad \text{(Eq. S-29)}$$

Output of the analyses are listed in Table S-7.

Table S-7. Percent Contribution to Temperature Variance Considering a High Porosity Zone in the Tiva Canyon

Lithostratigraphic Unit	Change in Temperature (C)	Percent Contribution
Crystal-Rich Tiva/Post Tiva	0.00	0.00%
Tpcp (2)	0.00	0.00%
TpcLD (3)	1.84	1.75%
Tpcpv3 (4)	0.45	0.43%
Tpcpv2 (5)	0.00	0.00%
Tpcpv1(6)	0.46	0.44%
Tpbt4 (7)	0.28	0.26%
Yucca (8)	0.04	0.03%
Tpbt3_dc (9)	1.39	1.32%
Pah (10)	11.88	11.25%
Tpbt2 (11)	0.13	0.12%
Tptrv3 (12)	0.13	0.12%
Tptrv2 (13)	0.13	0.12%
Tptrv1 (14)	0.04	0.03%
Tptrn (15)	3.89	3.68%
Tptrl (16)	0.00	0.00%
Tptpul	23.66	22.41%
Tptpmn	1.96	1.86%
Tptpll above	5.25	4.97%

Table S-7. Percent Contribution to Temperature Variance Considering a High Porosity Zone in the Tiva Canyon (Continued)

Lithostratigraphic Unit	Change in Temperature (C)	Percent Contribution
Tptpll below	7.80	7.39%
Tptpln	1.06	1.00%
Tptpln	0.26	0.25%
Tptpv3 (18)	33.44	31.68%
Tptpv2(19)	0.09	0.08%
Tptpv1(20)	0.09	0.08%
Tpbt1	1.84	1.74%
Calico	1.48	1.41%
Calico	1.49	1.41%
Calico	1.48	1.40%
Calico	1.49	1.41%
Calicobt	1.11	1.05%
Prowuv	1.56	1.48%
Prowuc	0.83	0.78%
Prowmd	0.031	0.03%
	105.58	100.00%

S7. CONCLUSIONS

An analysis was performed to assess the significance of the nonrepository horizon units on the uncertainty in repository temperature over extended periods (20,000 years). The analysis used the steady-state heat transfer by heat conduction in the vertical direction. The thermal conductivity under saturation conditions of both the repository and the nonrepository horizon units are included in this analysis. The analysis predicts an approximate increase in temperature (between 0°C and 6°C) after 1,000 years due to an average repository heat loading when maximum uncertainties are added to the nominal thermal conductivity values. This represents an extreme case, because the thermal conductivity uncertainties are multiplied by a factor of 1.96. An uncertainty analysis utilizing Hahn and Shapiro (1967 [DIRS 146529], p. 231) was performed, and predicted that the Tsw38 layer (Tptpv3) below the repository provides the most significant contribution to uncertainty over extended periods of time. This is because the rock-mass thermal conductivity of this unit is much lower (0.8 W/(m K)) than the rock-mass thermal conductivity of the repository horizon unit (1.89 W/(m K) under saturated conditions.

The steady-state analysis tends to overestimate the uncertainty of the nonrepository units because, in reality, heat diffuses more slowly from the repository horizon. The results show that immediately after closure, the variations in repository temperature (and, therefore, waste package temperature) are dominated by the uncertainty at the repository horizon.

The steady-state heat conduction analysis was repeated using an increased lithophysal porosity in the Tiva Canyon unit. This unit has lithophysal porosity with a rock fabric that is similar to the Topopah Spring unit. The analysis shows that uncertainty in thermal properties of the Tiva Canyon is not significant.

APPENDIX T

NOMENCLATURE AND COORDINATES FOR THERMAL CONDUCTIVITY BOREHOLES

Table T-1. Nomenclature and Coordinates for Thermal Conductivity Boreholes

Borehole ID	Casing Elevation (ft. MSL)	X_COORD (NV Stateplane Central ft.)	Y_COORD (NV Stateplane Central ft.)	Source DTN
UE-25 c #1	3709.11	569680.562	757096.750	MO9906GPS98410.000
UE-25 c #2	3715.29	569633.938	756849.625	MO9906GPS98410.000
UE-25 J-13	3319.44	579647.938	749202.000	MO9906GPS98410.000
UE-25 NRG #2	3803.02	569162.438	765763.750	MO9906GPS98410.000
UE-25 NRG #2a	3782.90	569001.062	765699.938	MO9906GPS98410.000
UE-25 NRG #2b	3803.08	569214.562	765765.250	MO9906GPS98410.000
UE-25 NRG #3	3826.33	568316.125	766250.625	MO9906GPS98410.000
UE-25 NRG #4	4101.64	566820.000	767080.188	MO9906GPS98410.000
UE-25 NRG #5	4108.66	564769.875	767889.625	MO9906GPS98410.000
UE-25 UZ #16	4001.58	564857.500	760535.125	MO9906GPS98410.000
UE-25 UZN #63	3944.06	566169.625	768837.250	MO9906GPS98410.000
USW H-1	4275.75	562388.438	770254.812	MO9906GPS98410.000
USW NRG-6	4093.02	564187.000	766726.500	MO9906GPS98410.000
USW NRG-7a	4208.52	562984.000	768880.125	MO9906GPS98410.000
USW SD-12	4343.17	561605.625	761956.562	MO9906GPS98410.000
USW SD-6	4906.42	558607.680	762421.390	MO9912GSC99492.000
USW SD-7	4474.99	561240.250	758949.875	MO9906GPS98410.000
USW SD-9	4274.97	561818.000	767998.500	MO9906GPS98410.000
USW UZ-14	4427.20	560141.562	771309.812	MO9906GPS98410.000
USW UZ-7	4170.96	562911.625	760837.000	MO9906GPS98410.000
USW UZ-7a	4230.23	562269.812	760692.750	MO9906GPS98410.000
USW WT-24	4902.36	562329.905	776703.061	MO9905LUSWWT24.000
USW UZ-N11	5223.72	559020.938	780573.938	MO9906GPS98410.000
USW UZ-N15	5109.43	559551.750	778090.562	MO9906GPS98410.000
USW UZ-N16	5116.65	559626.000	778150.812	MO9906GPS98410.000
USW UZ-N17	5127.55	559995.125	778224.125	MO9906GPS98410.000
USW UZ-N27	4859.42	558871.750	771569.375	MO9906GPS98410.000
USW UZ-N31	4153.84	562751.938	764245.625	MO9906GPS98410.000
USW UZ-N32	4158.10	562799.625	764302.625	MO9906GPS98410.000
USW UZ-N33	4331.26	561192.188	770070.125	MO9906GPS98410.000
USW UZ-N34	4323.76	561251.375	770158.750	MO9906GPS98410.000
USW UZ-N35	4247.41	562309.938	762264.000	MO9906GPS98410.000
USW UZ-N36	4642.23	563582.688	773899.500	MO9906GPS98410.000
USW UZ-N37	4123.59	563713.500	767499.125	MO9906GPS98410.000

Table T-1. Nomenclature and Coordinates for Thermal Conductivity Boreholes (Continued)

Borehole ID	Casing Elevation (ft. MSL)	X_COORD (NV Stateplane Central ft.)	Y_COORD (NV Stateplane Central ft.)	Source DTN
USW UZ-N38	4148.92	563343.875	767466.312	MO9906GPS98410.000
USW UZ-N53	4055.66	564237.250	760096.250	MO9906GPS98410.000
USW UZ-N54	4045.93	564262.188	760271.938	MO9906GPS98410.000
USW UZ-N55	4072.58	564248.250	760502.875	MO9906GPS98410.000
USW UZ-N57	4185.70	560829.812	755164.500	MO9906GPS98410.000
USW UZ-N58	4181.25	560862.188	755240.375	MO9906GPS98410.000
USW UZ-N59	4179.81	560888.375	755321.250	MO9906GPS98410.000
USW UZ-N61	4184.22	560893.938	755375.938	MO9906GPS98410.000
USW UZ-N62	4884.02	558302.688	757125.188	MO9906GPS98410.000
USW UZ-N64	4791.28	559435.500	765728.125	MO9906GPS98410.000

MSL = mean sea level
NOTE: The date of survey for each borehole is available in the source DTNs.

APPENDIX U

CORRELATION CHART FOR MODEL STRATIGRAPHY

Table U-1. Correlation Chart for Model Stratigraphy

Stratigraphic Unit[a]					Abbreviation[a]	PTn[a] and RHH[b]	Geologic Framework Model Unit
Group	Formation	Member	Zone	Subzone			
	Alluvium and Colluvium				Qal, Qc		Alluvium
Timber Mountain Group					Tm		
	Rainier Mesa Tuff				Tmr		
Paintbrush Group					Tp		
		Post-tuff unit “x” bedded tuff			Tpbt6		
		Tuff unit “x”[c]			Tpki (informal)		Crystal-Rich Tiva and Post-Tiva
		Pre-tuff unit “x” bedded tuff			Tpbt5		
	Tiva Canyon Tuff				Tpc		
		Crystal-Rich Member			Tpcr		
			Vitric zone		Tpcrv		
				Nonwelded subzone	Tpcrv3		
				Moderately welded subzone	Tpcrv2		
				Densely welded subzone	Tpcrv1		
			Nonlithophysal subzone		Tpcrn		
				Subvitrophyre transition subzone	Tpcrn4		
				Pumice-poor subzone	Tpcrn3		
				Mixed pumice subzone	Tpcrn2		
				Crystal transition subzone	Tpcrn1		
			Lithophysal zone		Tpcrl		
				Crystal transition subzone	Tpcrl1		
		Crystal-Poor Member			Tpcp		
			Upper lithophysal zone		Tpcpul		
				Spherulite-rich subzone	Tpcpul1		
			Middle nonlithophysal zone		Tpcpmn		
				Upper subzone	Tpcpmn3		
				Lithophysal subzone	Tpcpmn2		
				Lower subzone	Tpcpmn1		Tpcp
			Lower lithophysal zone		Tpcpll		
				Hackly fractured subzone	Tpcpllh		
			Lower nonlithophysal zone		Tpcpln		
				Hackly subzone	Tpcplnh		
				Columnar subzone	Tpcplnc		TpcLD

Table U-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit[a] (Group / Formation / Member / Zone / Subzone)	Abbreviation[a]	PTn[a] and RHH[b]	Geologic Framework Model Unit
Vitric zone	Tpcpv		
Densely welded subzone	Tpcpv3		Tpcpv3
Moderately welded subzone	Tpcpv2		Tpcpv2
Nonwelded subzone	Tpcpv1		Tpcpv1
Pre-Tiva Canyon bedded tuff	Tpbt4		Tpbt4
Yucca Mountain Tuff	Tpy		Yucca
Pre-Yucca Mountain bedded tuff	Tpbt3		Tpbt3_dc[d]
Pah Canyon Tuff	Tpp	PTn	Pah
Pre-Pah Canyon bedded tuff	Tpbt2		Tpbt2
Topopah Spring Tuff	Tpt		
Crystal-Rich Member	Tptr		
Vitric zone	Tptrv		
Nonwelded subzone	Tptrv3		Tptrv3
Moderately welded subzone	Tptrv2		Tptrv2
Densely welded subzone	Tptrv1		Tptrv1
Nonlithophysal zone	Tptrn		
Dense subzone	Tptrn3		
Vapor-phase corroded subzone	Tptrn2		
Crystal transition subzone	Tptrn1		Tptrn
Lithophysal zone	Tptrl		
Crystal transition subzone	Tptrl1		Tptrl
Crystal-Poor Member	Tptp		
Lithic-rich zone	Tptpf or Tptrf		Tptf
			Tptpul
Upper lithophysal zone	Tptpul	RHH	RHHtop
Middle nonlithophysal zone	Tptpmn		
Nonlithophysal subzone	Tptpmn3		
Lithophysal bearing subzone	Tptpmn2		
Nonlithophysal subzone	Tptpmn1		Tptpmn
Lower lithophysal zone	Tptpll		Tptpll
Lower nonlithophysal zone	Tptpln		Tptpln
Vitric zone	Tptpv		
Densely welded subzone	Tptpv3		Tptpv3
Moderately welded subzone	Tptpv2		Tptpv2

Table U-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit[a]					Abbreviation[a]	PTn[a] and RHH[b]	Geologic Framework Model Unit
Group	Formation	Member	Zone	Subzone			
				Nonwelded subzone	Tptpv1		Tptpv1
		Pre-Topopah Spring bedded tuff			Tpbt1		Tpbt1
	Calico Hills Formation				Ta		Calico
		Bedded tuff			Tacbt		Calicobt
Crater Flat Group					Tc		
	Prow Pass Tuff				Tcp		
			Prow Pass Tuff upper vitric nonwelded zone		(Tcpuv)[e]		Prowuv
			Prow Pass Tuff upper crystalline nonwelded zone		(Tcpuc)[e]		Prowuc
			Prow Pass Tuff moderately densely welded zone		(Tcpmd)[e]		Prowmd
			Prow Pass Tuff lower crystalline nonwelded zone		(Tcplc)[e]		Prowlc
			Prow Pass Tuff lower vitric nonwelded zone		(Tcplv)[e]		Prowlv
		Pre-Prow Pass Tuff bedded tuff			(Tcpbt)[e]		Prowbt
	Bullfrog Tuff				Tcb		
			Bullfrog Tuff upper vitric nonwelded zone		(Tcbuv)[e]		Bullfroguv
			Bullfrog Tuff upper crystalline nonwelded zone		(Tcbuc)[e]		Bullfroguc
			Bullfrog Tuff welded zone		(Tcbmd)[e]		Bullfrogmd
			Bullfrog Tuff lower crystalline nonwelded zone		(Tcblc)[e]		Bullfroglc
			Bullfrog Tuff lower vitric nonwelded zone		(Tcblv)[e]		Bullfroglv
		Pre-Bullfrog Tuff bedded tuff			(Tcbbt)[e]		Bullfrogbt
	Tram Tuff				Tct		
			Tram Tuff upper vitric nonwelded zone		(Tctuv)[e]		Tramuv
			Tram Tuff upper crystalline nonwelded zone		(Tctuc)[e]		Tramuc
			Tram Tuff moderately densely welded zone		(Tctmd)[e]		Trammd
			Tram Tuff lower crystalline nonwelded zone		(Tctlc)[e]		Tramlc
			Tram Tuff lower vitric nonwelded zone		(Tctlv)[e]		Tramlv

Table U-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit[a]					Abbreviation[a]	PTn[a] and RHH[b]	Geologic Framework Model Unit
Group	Formation	Member	Zone	Subzone			
		Pre-Tram Tuff bedded tuff			(Tctbt)[e]		Trambt
		Lava and flow breccia (informal)			Tll		
		Bedded tuff			Tllbt		
	Lithic Ridge Tuff				Tr		
		Bedded tuff			Tlrbt		
		Lava and flow breccia (informal)			Tll2		
		Bedded tuff			Tllbt		
		Lava and flow breccia (informal)			Tll3		
		Bedded tuff			Tll3bt		Tund
		Older tuffs (informal)			Tt		
			Unit a (informal)		Tta		
			Unit b (informal)		Ttb		
			Unit c (informal)		Ttc		
		Sedimentary rocks and calcified tuff (informal)			Tca		
		Tuff of Yucca Flat (informal)			Tyf		
Pre-Tertiary sedimentary rock							
	Lone Mountain Dolomite				Slm		
	Roberts Mountain Formation				Srm		Paleozoic

Source: *Geologic Framework Model (GFM2000)* (BSC 2004 [DIRS 170029], Table 6-2).

NOTE: Shaded rows indicate header lines for subdivided units.

[a] DTN MO9510RIB00002.004 [DIRS 103801].
[b] CRWMS M&O 1997 [DIRS 100223], pp. 43 to 50.
[c] Correlated with the rhyolite of Comb Peak (Buesch et al. 1996 [DIRS 100106], Table 2).
[d] Includes rhyolite of Delirium Canyon north of Yucca Wash (DTN GS980608314221.002 [DIRS 107024]).
[e] For the purposes of GFM2000, each formation in the Crater Flat Group was subdivided into six zones based on the requirements of the users of the geologic framework model. The subdivisions are upper vitric (uv), upper crystalline (uc), moderately to densely welded (md), lower crystalline (lc), lower vitric (lv), and bedded tuff (bt) (Buesch and Spengler 1999 [DIRS 107905], pp. 62 to 64).

PTN = Paintbrush nonwelded hydrologic unit; RHH = Repository Host Horizon

APPENDIX V

QUALIFICATION OF UNQUALIFIED DRY BULK DENSITY DATA CONTAINED IN DTN: GS920408312314.011, SEP TABLE S97135_0002 AND DTN: GS930408312132.007, SEP TABLE S97276_001 FOR USE IN MDL-NBS-GS-000006, REV 01

This appendix presents the documentation for the data qualification of unqualified project data used as direct input only to this report. This data qualification has been performed in accordance with AP-SIII.2Q, Rev. 1 ICN 2, *Qualification of Unqualified Data*.

Data for Qualification

Product Output DTN SN0303T0503102.008 contains the average and standard deviation for saturated thermal conductivity, dry thermal conductivity, matrix porosity, and dry bulk density for the nonrepository GFM (BSC 2004 [DIRS 170029]) units. Two data tracking numbers (DTNs) that provide dry bulk density values to develop DTN SN0303T0503102.008 are unqualified. The applicable data to be qualified for intended use in this report are:

1. GS920408312314.011 [DIRS 129660], Geohydrology of Test Well USW H-1, Yucca Mountain, Nye County, Nevada.

   The dry bulk density data for this DTN are contained in SEP table S97135_002.

2. GS930408312132.007 [DIRS 129625], Geohydrologic Data and Test Results from Well J-13, Nevada Test Site, Nye County, Nevada.

   The dry bulk density data for this DTN are contained in SEP table S97276_001.

Methods of Qualification Selected

The method selected for qualification is corroborating data. The unqualified dry bulk density data sets from test wells USW H-1 and J-13 are compared to the qualified dry bulk density data from DTNs listed at the bottom of Table V-1. The rationale for this method is that if the unqualified dry bulk density data sets are in agreement to within the range of uncertainty established for model validation, the unqualified data can be considered qualified for intended use within this report.

Evaluation Criteria

The dry bulk density values in the two unqualified DTNs will be considered qualified for intended use if the difference in mean values of qualified versus unqualified data is within the 95-percent confidence level. Specifically, if the normalized difference in mean values (column "t" in Table V-2) has an absolute value less than 1.96, then the data are considered qualified.

Evaluation of the Technical Correctness of the Data

Table V-1 contains the unqualified dry bulk density values from DTN GS920408312314.011 ([DIRS 129660], SEP table S97135_002) and DTN GS930408312132.007 ([DIRS 129625], SEP table S97276_001), and organizes the data according to layer characterization as presented in Table 6-13 of this report. Table V-1 also contains averaged qualified data; note that the data in Table V-1 are the same data presented in Table 6-13, but are split into sets, a small set of unqualified data from two wells (USW H-1 and J-13), and a large set of qualified data from the twenty-two remaining wells listed in Table 4-5.

Table V-1. Qualified and Unqualified Dry Bulk Density Data

Well Name	GFM Unit	Layer Type	Unqualified Dry Bulk Density Data: Meas. Value (g/cm^3)	Unqualified: Mean (g/cm^3)	Unqualified: # points	Unqualified: Std Dev	Qualified Dry Bulk Density Data: Mean (g/cm^3)	Qualified: Std Dev	Qualified: # points
H-1	Tptrn	Welded	2.0				2.19	0.177	1314
H-1	Tptrn	Welded	2.0				2.19	0.177	1314
H-1	Tptrn	Welded	2.0				2.19	0.177	1314
H-1	Tptrn	Welded	2.1				2.19	0.177	1314
H-1	Tptrn	Welded	2.2				2.19	0.177	1314
H-1	Tptrn	Welded	2.2				2.19	0.177	1314
H-1	Tptrn	Welded	2.2				2.19	0.177	1314
H-1	Tptrn	Welded	2.2				2.19	0.177	1314
J-13	Tptrl	Welded	2.08	2.11	9	0.093	2.19	0.177	1314
J-13	Tptpv3	Vitric	2.31				2.31	0.087	116
J-13	Tptpv3	Vitric	2.12	2.22	2	0.134	2.31	0.087	116
H-1	Pah	Non-welded	1.3				1.46	0.338	588
H-1	Yucca	Non-welded	1.3				1.46	0.338	588
H-1	Yucca	Non-welded	1.4				1.46	0.338	588
J-13	Tpbt2	Non-welded	1.05				1.46	0.338	588
J-13	Tpbt2	Non-welded	1.76				1.46	0.338	588
J-13	Tptpv2	Non-welded	1.60	1.40	6	0.250	1.46	0.338	588
H-1	Calicobt	Calico	1.3				1.68	0.157	608
H-1	Calicobt	Calico	1.4				1.68	0.157	608
J-13	Calicobt	Calico	1.73	1.48	3	0.225	1.68	0.157	608
H-1	Prowlv	Non-welded (prow)	1.7				1.79	0.118	504
H-1	Prowlv	Non-welded (prow)	1.7				1.79	0.118	504
H-1	Prowlv	Non-welded (prow)	1.7				1.79	0.118	504
J-13	Prowbt	Non-welded (prow)	1.74	1.71	4	0.020	1.79	0.118	504
H-1	Bullfrogbt	Non-welded (bull)	1.8				1.89	0.162	61
H-1	Bullfroguc	Non-welded (bull)	2.1				1.89	0.162	61
H-1	Bullfroguc	Non-welded (bull)	1.9				1.89	0.162	61
H-1	Bullfroguv	Non-welded (bull)	1.6				1.89	0.162	61
H-1	Bullfroguv	Non-welded (bull)	1.6				1.89	0.162	61
H-1	Bullfroguv	Non-welded (bull)	1.6				1.89	0.162	61
J-13	Bullfroguc	Non-welded (bull)	1.92	1.79	7	0.197	1.89	0.162	61
H-1	Bullfrogmd	Welded (bull)	2.0				2.27	0.130	87
H-1	Bullfrogmd	Welded (bull)	2.1				2.27	0.130	87
H-1	Bullfrogmd	Welded (bull)	2.1				2.27	0.130	87
H-1	Bullfrogmd	Welded (bull)	2.1				2.27	0.130	87
J-13	Bullfrogmd	Welded (bull)	1.89				2.27	0.130	87
J-13	Bullfrogmd	Welded (bull)	2.07	2.04	6	0.085	2.27	0.130	87
H-1	Tramlv	Non-welded (tram)	2.0				1.67	0.130	26
H-1	Tramlv	Non-welded (tram)	2.0				1.67	0.130	26
H-1	Tramlv	Non-welded (tram)	2.0				1.67	0.130	26
H-1	Tramlv	Non-welded (tram)	2.2				1.67	0.130	26
H-1	Tramlv	Non-welded (tram)	2.1				1.67	0.130	26
H-1	Tramlv	Non-welded (tram)	2.1				1.67	0.130	26
H-1	Tramuv	Non-welded (tram)	1.8				1.67	0.130	26
H-1	Tramuv	Non-welded (tram)	1.8				1.67	0.130	26
H-1	Tramuv	Non-welded (tram)	2.0				1.67	0.130	26
J-13	Tramlc	Non-welded (tram)	1.93				1.67	0.130	26
J-13	Tramuv	Non-welded (tram)	1.95	1.99	11	0.121	1.67	0.130	26

Table V-1. Qualified and Unqualified Dry Bulk Density Data (Continued)

Well Name	GFM Unit	Layer Type	Unqualified Dry Bulk Density Data: Meas. Value (g/cm^3)	Mean (g/cm^3)	# points	Std Dev	Qualified Dry Bulk Density Data: Mean (g/cm^3)	Std Dev	# points
J-13	Trammd	Welded (tram)	2.09	2.15	2	0.078	N/A	N/A	0
J-13	Trammd	Welded (tram)	2.20				N/A	N/A	0

NOTES:

Sources of unqualified data:

DTN GS930408312132.007 [DIRS 129625]

DTN GS920408312314.011 [DIRS 129660]

Sources of qualified data:

DTN MO0004QGFMPICK.000 [DIRS 152554] DTN GS000508312231.006 [DIRS 153237]

DTN SNL01A05059301.007 [DIRS 108980] DTN SNL02030193001.002 [DIRS 120575]

DTN GS000408312231.004 [DIRS 149582] DTN GS950308312231.002 [DIRS 108990]

DTN GS950408312231.004 [DIRS 108986] DTN GS940508312231.006 [DIRS 107149]

DTN GS930108312231.006 [DIRS 108997] DTN GS920508312231.012 [DIRS 109001]

DTN GS940408312231.004 [DIRS 109000] DTN GS951108312231.009 [DIRS 108984]

DTN GS951108312231.010 [DIRS 108983] DTN GS951108312231.011 [DIRS 108992]

DTN GS960808312231.004 [DIRS 108985] DTN GS980708312242.010 [DIRS 106752]

DTN GS980808312242.014 [DIRS 106748] DTN SNL02030193001.004 [DIRS 108415]

DTN SNL02030193001.008 [DIRS 120597] DTN SNL02030193001.003 [DIRS 120578]

DTN SNL02030193001.006 [DIRS 120579] DTN SNL02030193001.013 [DIRS 120614]

DTN SNL02030193001.005 [DIRS 122545] DTN SNL02030193001.007 [DIRS 120582]

DTN SNL02030193001.014 [DIRS 109609] DTN SNL02030193001.015 [DIRS 120617]

DTN SNL02030193001.009 [DIRS 109614] DTN SNL02030193001.012 [DIRS 108416]

DTN SNL02030193001.022 [DIRS 109613] DTN SNL02030193001.016 [DIRS 120619]

DTN SNL02030193001.017 [DIRS 109610] DTN SNL02030193001.018 [DIRS 109611]

DTN SNL02030193001.019 [DIRS 108431] DTN SNL02030193001.020 [DIRS 108432]

DTN SNL02030193001.021 [DIRS 108433] DTN SNL01A05059301.002 [DIRS 150042]

Qualified data are extracted from Output DTN: SN0307T0503102.009, files *Input\QVDry Bulk-Dens*.dat*

N/A = Not available.

As can be seen in Table V-1, when the number of data points are summed for qualified and unqualified data, the total equals the number of data points listed in Table 6-13. The same correlation method (DTN MO0004QGFMPICK.000 [DIRS 152554]) used to assign dry bulk density values to rock layer types (i.e., welded, calico) in Table 6-13 is used to classify dry bulk density values for Table V-1. The Microsoft program Excel was used to calculate statistical values such as the mean, standard deviation, and variance for each rock layer.

It should be noted that the two dry bulk density values for GFM unit Trammd came solely from unqualified DTN GS930408312132.007 [DIRS 129625] because no corroborating data from other data sources could be identified for this GFM unit.

Data Generated by the Evaluation

Table V-2 was generated by using Equation 7-1 and Equation 7-2, and data from Table V-1. All values listed in column "t" are less than 1.96; therefore, DTN GS930408312132.007 [DIRS 129625] and DTN GS920408312314.011 [DIRS 129660] are qualified based on the evaluation criteria.

Table V-2. Comparison of Means for Qualified and Unqualified Data

Layer Type	Qualified Data				Unqualified Data				ν	$s_{combined}$	t
	N_1	μ_1	s_1	S_1	N_2	μ_2	s_2	S_2			
Welded	1314	2.19	0.177	232.898	9	2.11	0.093	0.840	1321	6.408	0.04
Vitric	116	2.31	0.087	10.149	2	2.22	0.134	0.269	116	0.943	0.15
Non-welded	588	1.46	0.338	198.724	6	1.40	0.250	1.499	592	8.168	0.02
Calico	608	1.68	0.157	95.284	3	1.48	0.225	0.675	609	3.861	0.09
Prow Pass nonwelded	504	1.79	0.118	59.267	4	1.71	0.020	0.080	506	2.635	0.06
Prow Pass welded	81	2.07	0.139	11.259	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bullfrog nonwelded	61	1.89	0.162	9.897	7	1.79	0.197	1.381	66	1.230	0.21
Bullfrog welded	87	2.27	0.130	11.347	6	2.04	0.085	0.507	91	1.191	0.46
Tram Tuff nonwelded	26	1.67	0.130	3.385	11	1.99	0.121	1.330	35	0.615	-1.45
Tram Tuff welded [a]	81	2.07	0.139	11.259	2	2.15	0.078	0.156	81	1.251	-0.08

[a] The Prow Pass welded layer is selected as a surrogate for the Tram Tuff welded layer because no qualified data are available. The same layer substitution was done for matrix porosity in Section 6.5 and is reasonable because of the proximity of layers.

N/A = Not available.

Because no Prow Pass welded data were acquired from test wells USW H-1 and J-13, no statistics are shown in Table V-2 for unqualified data pertaining to the Prow pass welded layer.

Because there are no dry bulk density data for the welded Tram Tuff layer, the results for the Prow Pass welded layer are used for Trammd, because of the proximity of the layers and the similarity between the rock types of the two layers.)

Only standard spreadsheet functions were used in the generation of data contained in Table V-1; such software usage is exempt from software qualification per Section 2.1.6 of LP-SI.11Q-BSC, *Software Management*.

Evaluation Results

Based upon the comparisons made above, and based upon the experience of the data qualification team, the data from DTN GS920408312314.011 ([DIRS 129660], SEP table S97135_002) and from DTN GS930408312132.007 ([DIRS 129625], SEP table S97276_001) are qualified for use in this report.

Rationale for Abandoning Any Qualification Methods, if Appropriate

No qualification methods were abandoned.

Limits or Caveats To Be Considered by Potential Users of the Data

No limits or caveats have been identified which would apply to the use of these data within this report.

Identification of Any Supporting Information Used in the Qualification Effort

No supporting information, other than data and reports previously mentioned in the report, were used in the qualification effort.

Data Qualification Plan

The data in this appendix are qualified in accordance with the *Data Qualification Plan, Qualification of Unqualified Dry Bulk Density Data Contained in DTNs GS920408312314.011, SEP Table S97135_002 and DTN GS930408312132.007, SEP Table S97276_001 for Use in MDL-NBS-GS-000006 Rev 01* (BSC 2004 [DIRS 171956]).

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